THE SIGNIFICANCE OF SKELETAL AND DENTAL MEASUREMENTS OBTAINED FROM A PANOREX RADIOGRAPH

By

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INTRODUCTION

Use of panoramic dental radiography has increased steadily in recent years, and there are several reasons for its increased popularity. More general information can be obtained from a panoramic survey than from the complete intraoral radiographic survey. A panoramic radiograph includes an image of the entire dento-facial complex from the lower border of the mandible to the inferior border of the orbits and posteriorly to the external auditory meatus. It provides a view of all structures within this area, including the maxillary sinus, temporomandibular joint, ramus and body of the mandible, maxillary tuberosity, teeth and various areas of soft tissue including the tongue.

The panoramic radiograph is valuable not only because relationships can be established between structures within the area described, but also because many types of pathologic processes in the hard tissue can be readily surveyed. Although panoramic radiography is not considered adequate for the diagnosis of incipient carious lesions, large carious lesions can easily be observed. An obvious benefit of panoramic radiography in the oral health care of children is that it facilitates an accurate determination of the status of the developing primary and permanent dentitions.

The broad overview available in panoramic radiography has become a valuable adjunct to the complete intraoral radiographic survey used by most practitioners. By using panoramic radiography to supplement a complete-mouth survey, or in conjunction with posterior bitewings to determine the diagnosis, the practitioner can record more complete findings which might lie outside the area visible in the complete-mouth survey.

Although panoramic radiography furnishes the dental practitioner with much information, it would be even more valuable if it could be used to determine skeletal measurements of the head. This would allow an estimate to be made of the patient's current osseous growth status, similar to that obtained from a lateral cephalometric headplate. The purpose of this investigation was to determine whether measurements from tracings of a Panorex radiograph provide a valid comparison to bony relationships identified on the lateral cephalometric headplate.

REVIEW OF LITERATURE

This literature review will consist of two main sections: A brief overview of the development and uses of radiographic cephalometry and a survey of the history and types of laminography, including a detailed account of the development of Panorex laminography.

DEVELOPMENT AND USES OF RADIOGRAPHIC CEPHALOMETRY

Radiographic cephalometry dates back to 1931 when Broadbent[1] introduced to the scientific community a new cephalometric method and its results at the Bolton Foundation in Cleveland. This method of diagnosis proved to be an invaluable adjunct in the study of normal and abnormal cranial development. Other investigators adapted radiographic cephalometry to their own studies of growth and development, and their discoveries have led to a better understanding of problems encountered in the development of the dental-facial skeleton.

Initially, radiographic cephalometry was employed mainly as a research tool in studying the growth and development of the head, including both normal and abnormal developmental patterns. In time, however, it also gained recognition as an invaluable aid to clinicians in the diagnosis, treatment planning and prognosis of malocclusions. Through the use of the Broadbent-Bolton Cephalometer, Broadbent provided a much improved method for the quantitative assessment of dento-facial growth.[2]

Broadbent[3] in 1937 reported on the use of both angular and linear measurements to assess cranial and dento-facial growth, but not until Downs[4] published his work in 1948 was interest in radiographic cephalometry revived. Downs evaluated twenty individuals 12 to 17 years of age with excellent occlusions and correlated skeletal and dental function and denture patterns, establishing a range of normal for early adult dentitions. He also gave examples of the use of lateral cephalometric headplates in case analysis. Models, photographs, intraoral radiographs and a single lateral cephalometric headplate were taken of each patient. Cephalometric tracings were made of all the lateral headplates. One linear and nine angular measurements were made on each patient's cephalometric tracing. Downs concluded that there is a facial pattern which represents mean or average form for individuals possessing excellent occlusions. Notable deviations exist on both sides of the mean findings of the facial pattern. Excessive deviations from the means usually express abnormalities of relationship which will be evident as skeletal or dental disharmonies. The lateral skeletal and dental pattern can be quantitated and appraised as good or bad according to the amount of deviation of the readings from the known mean pattern. Such analysis tends to point out the desirable tooth movement indicated in treatment. Downs recognized that although the technique employed in radiographic cephalometry was not without some error, the information could be of considerable value in forming a treatment prognosis.

Adams[5] in 1940 developed a set of scales to correct the error due to enlargement in the lateral cephalometric headplate. The outline of the radiograph was approximately 5% larger than the actual patient being radiographed. Other distortions in the radiographic procedure included blurring of the images due to secondary radiation, and variations in kilovolt peak (KVP) and milliampers (MA) resulting in variations in both density and contrast. Most important in minimizing distortion was the correct positioning of the patient in the cephalostat.[6]

Throughout the early 1950's many authors expounded on the use of cephalometrics in orthodontics. They were convinced that the information derived from a cephalometric radiograph could be used in orthodontic diagnosis and treatment.[7-12] Each of these investigators defined cephalometric measuring points and interpreted the measurements. They were interested in the reliability and validity of each measurement, its significance in case analysis and the range of norms.

To help eliminate confusion arising from the different cephalometric analyses, the American Association of Orthodontics in March of 1957 sponsored the first radiographic cephalometric workshop at the Bolton Fund Headquarters at Western Reserve University, Cleveland, Ohio.[10] The group included orthodontists, researchers, and anthropologists. They attempted to develop standardized cephalometric radiographic techniques. Also at this workshop, a common understanding was developed of the different cephalometric landmarks and measurements, both linear and angular, which were subsequently validated by studies using radiographs of disarticulated skulls.[13, 14]

The information derived from cephalometric radiography can be an invaluable aid in the management of patients during both diagnosis and treatment. However, there are definite limitations to the technique.

The results from the cephalometric interpretation can be used only as a guide to help formulate an individual treatment plan. Although the different cephalometric measurements are compared to average for individual age groups, average patients are not treated -- only individuals. Individual patients can be within the norm of their particular growth pattern, be very acceptable for that individual, yet be outside the range of normal for the age group.[15]

DEVELOPMENT AND USES OF LAMINOGRAPHY

HISTORY OF LAMINOGRAPHY

Laminography is a radiographic technique by which one may select a flat plane within an object and project this plane in sharp focus on a radiographic film. Other planes outside the focal trough are blurred and not projected on the film. Terms that have been variously applied to this technique are laminography, planigraphy, tomography, and body section radiography. The fundamental principle of laminography is that the tube and film move during the exposure in such a way that the radiographic shadow or image of a selected plane in a body remains stationary on the moving film. The shadows of all other planes have a relative displacement on the film, and are therefore blurred to varying degrees depending on the distance of such planes from the one selected. This method of projecting a plane or section of a solid object is accomplished by moving the point of emission of the x-ray in one direction while the recording medium is moving in the opposite direction. The two are moved simultaneously in a constant ratio by means of a connecting system which rotates about an axis lying in the plane of the section to be projected[16] (Figure 1).

Bocage in 1921 discovered the principle involved in body section radiography and filed a French patent.[17] He proposed three different methods for using the machine, although no practical model was built. One of these methods came very close to duplicating that of the modern Panorex equipment. Contributions by others in the early years of laminography are covered in detail in an article by Andrews.[17]

Kieffer[18] in 1938 reported on his independent discovery 10 years earlier of the principle involved in body section radiography. Kieffer had designed a practical machine by 1929,but due to poor health, the depression, and scepticism on the part of financial backers, he was unable to have a machine built until 1936. He described his machine as a flat table with tube head and film which moved, while the patient was stationary. The image layer produced was 5 mm deep on the average.

TYPES OF LAMINOGRAMS

Not until the late 1940's and early 1950's was the principle of laminography applied to the jaws. Since that time the principle has been used in a number of machines and it has been applied to curved surfaces such as the jaws in an attempt to get a clear, undistorted view of a selected layer of structures. This is termed curved surface laminography.

The principles employed in curved surface laminography were described independently in Finland by Paatero[19] in 1948 and in this country by Smathers[20] in 1949. Nelson and Kumpula[21] in 1952 described a machine developed at the University of Washington. In their machine the film was placed intraorally and the x-ray tube traveled horizontally along the buccal segment until it reached the anterior segment. There it stopped. The anterior segment was exposed in a circular movement by rotating the chair in which the patient was seated until it reached the edge of the opposing buccal segment. Here the chair stopped again and the x-ray tube resumed its horizontal migration (Figure 2). In this manner the machine was able to expose both maxillary and mandibular arches on one film. The film produced by this machine or this method of radiography has been termed panographic radiography.

Paatero[22] in 1949 described the development and construction of a machine which applied the tomographic principle to the radiographing of curved surfaces. His machine used an x-ray source and a patient seated between the x-ray source and a 24 X 30 centimeter film. The film was semicylindric to conform to the shape of the head. It was placed in front of the face and held between intensifying screens by a cassette. The patient was seated in a chair constructed to rotate 180 degrees to give a complete picture of the anterior area. Paatero was thus able to obtain a radiograph of the entire front of the face.

Paatero, Nelson, and Kumpula have contributed the basic principles of the two types of machines used today in curved surface laminography. From the machine first described by Nelson and Kumpula has come the Panorex, and from the machine described by Paatero has developed the Orthopantomograph.

In Paatero's initial report he named the method of radiography, "pantomography," a contraction of the words panoramic and tomography. In a subsequent publication[23] he described the principles involved in curved surface laminography and some of its variations. He explained patient positioning, the image layer, and the nomenclature used in pantomography. In Paatero's first machine the object rotated around one axis. It gave better detail than a laminogram, but since it had only one axis of rotation, it could only be used to diagnose gross changes.

Paatero[24] in 1961 described a method by which double eccentric pantomograms could be taken. He used three axes of rotation to give a much improved radiograph since the image layer would more nearly encompass the entire jaw area. Paatero did the theoretical study and preliminary experiments on the Orthopantomograph as early as 1954 and in 1958 he built a miniature apparatus of the Orthopantomograph for experimenting with dry skulls. The "patient" sat immobilized while the x-ray tube and curved cassette holder with plastic cassette rotated about his head. Concurrently the cassette holder rotated about its own rotational axis. The tube and the axis of the cassette holder were attached to a horizontal bar which turned successively about three axes of rotation, one for each buccal segment and one for the anterior area (Figure 3).

Not until the mid 1960's did the Orthopantomograph receive significant recognition in the United States. Two other types of panoramic radiographs are currently available. The Panoramix developed by Ott of Switzerland and modified by Blackman of England is one type. The dental hard tissue structures are projected on two separate radiographs. The film is placed in a curved manner on the outside of the face and an intraoral radiation source from a specially designed tube is used (Figures 4 and 5). This machine is still largely experimental. It "...cannot be considered a conventional x-ray installation, and in fact, falls in the category defined by NCRP /‾National Council on Radiation Protection[25]‾/ Report No. 35 as, '...experimental devices requiring appropriate evaluation by a qualified expert.' "[26] In England, Blackman[27,28] built a machine which is a variation of the Orthopantomograph. Instead of the tube head rotating, the patient rotates and the tube head is stationary (Figure 6). This machine is called the Rotograph. Recently, the General Electric Company developed a machine they call the GE 3000. Instead of having three axes of rotation, it has a continuous axis of rotation. It can be adjusted to different pre-selected layers depending on the size of the patient's jaw[29,30] (Figures 7 and 8). A number of Japanese manufacturers have marketed machines similar in design and function to the Orthopantomograph except that they use different head holders.

PANOREX LAMINOGRAPHY

This section will review the following topics, as they relate to Panorex radiography: development of the machine, anatomic structures, radiation, image distortion, advantages and disadvantages, specific clinical uses, uses in orthodontic diagnosis, and cephalostats.

THE DEVELOPMENT OF PANOREX LAMINOGRAPHY

Paatero spent eighteen months at the University of Washington. It was modifications of his technique that led to the development of the Panorex. Using the findings of Nelson and Kumpula at the University of Washington in 1950-1951, the National Bureau of Standards (NBS) in cooperation with the United States Air Force Dental Service and the United States Air Force School of Aviation Medicine first described the development of a panoramic x-ray machine.[31] The machine was developed by Col. D. C. Hudson, temporarily assigned to the NBS from the United States Air Force Dental Service and J. W. Kumpula of the NBS staff, with the cooperation of the members of the NBS Electronics Instrumentation Laboratory. The machine was described as having an x-ray source and film holding device which followed semicircular paths on opposite sides of the patient's stationary head. The film holder traveled in front of the patient and the x-ray source behind him. Movements of the source and film were so coordinated that only those structures of the dental arch in the finished film were sharply projected, while other overlying structures were not. The x-ray source and film holder were suspended from opposite ends of a horizontal arm that rotated about a central vertical axis. A narrow beam of radiation from a slit in the cone of the x-ray source passed through the subject's head and entered a corresponding slit in the film holder just beyond the patient's head. Meanwhile, the film in a carrier within the holder traveled horizontally in a direction opposite that of the holder and at such a rate that an x-ray shadow of each successive tooth fell on successive areas of the film.

The first description of the machine from the Technical News Bulletin[31] (National Bureau of Standards) noted that the panoramic device produced lower radiation levels than the conventional fourteen film intraoral technique.

Hudson, Kumpula, and Dickson[32] first reported on their prototype machine for panoramic radiography in January, 1957. They described the machine's mathematical derivation, construction, operation, and the method by which it obtained the desired results. From this prototype the present-day Panorex was built and commercially produced by the S.S. White Dental Manufacturing Company.

Dental Industry News in March, 1959[33] announced the development of the Panorex by the XRM (X-Ray Manufacturing Corporation of America) a subsidiary of the S.S. White Dental Manufacturing Company (Figure 9). The Panorex technique employed the principle of curved surface laminography but it differed from the technique initially described by Nelson and Kumpula[21] in that the patient's head remained stationary while the film and x-ray source rotated around it. In addition, the axis of rotation was changed from one side to the other midway through the exposure to symmetrically position the right and left sides of the patient on the film and minimize distortion.

A flat cassette carrier for the film was mounted on one end of a horizontal arm and the x-ray head on the opposite end. The image and film were synchronized by rotating the x-ray source and cassette holder lineally about the patient's head by means of a cable passing around a cam shaped to simulate the curve of the dental arch. The change in the axis of rotation was accomplished by an automatic shift of the chair midway through the cycle (Figure 10). During this shift the midportion of the film became blurred because of the movement and was excluded from the finished radiograph. An uninterrupted view of the radiograph was accomplished by some practitioners with the technique of cutting out the midportion of the film and splicing the two halves together. The midportion of the film should be included for medico-legal reasons. Cutting and splicing is considered altering or tampering with the film thus making it unacceptable as evidence in some courts of law.[34] This blurred area has been eliminated in the newer Panorex machines. The radiation is cut off during the time the chair shifts, thus reducing exposure to the spinal column and resulting in a clear area between the two halves of the radiograph.[35]

Kraske and Mazzarella[36] in 1961 conducted one of the first evaluations of the Panorex. The evaluation was by selected members of the Dental Department of the U.S. Naval Training Center and U.S. Naval Hospital, Great Lakes, Illinois. They took Panorex radiographs of 905 Naval recruits, divided into four groups. Group A consisted of 500 recruits whose oral conditions were examined according to standardized procedures, using bitewings, mirror and explorer. The charting was considered the true oral picture and was compared to the charting made only from the Panorex radiograph. Group B contained 169 recruits whose oral conditions were charted as in Group A. Comparisons were then drawn to a re-examination consisting of a rapid clinical examination with a Panorex radiograph used as an adjunct. Group C had 120 recruits on whom charting was done using a Panorex and rapid clinical examinations. This was compared to complete-mouth radiographs of these patients and a more definitive oral examination. For the 116 recruits in Group D, only a Panorex radiograph was taken. It was used by oral surgeons, prosthodontists and periodontists to make a diagnosis and treatment plan involving extensive operative, surgical, and prosthetic procedures without the use of conventional radiographs or dental examination records. No mention was made of how evaluators for this study were selected, nor under what conditions the comparisons were analyzed or if measures were taken to rule out bias.

These investigators concluded that the Panorex was effective for all phases of diagnosis, including proximal caries, although small lesions were hard to identify.

Several recommendations for improvement of the Panorex were offered. Excessive film grain should be reduced by increasing the KVP to 70 and the MA to 10. Head movement should be diminished by designing a more stable chin rest. Overlapped proximal contacts should be eliminated by using an adjustable rotary mechanism to conform to the different arch forms. Clearance between the camera and the patient's head needs to be increased. Kraske and Mazzarella discovered that a slight downward tilting of the occlusal plane improved the quality and definition of the temporomandibular joint (TMJ) area. When the occlusal plane was tilted upward, the TMJ projection was lost and the radiopacity of the palatal vault was superimposed on the apices of the maxillary teeth, blotting them out.

The S.S. White Company incorporated many of these recommendations into their Panorex machine, such as creating a more stable chin rest, increasing the KVP and MA, allowing more clearance between the x-ray tube and the patient's head, and suggesting in their operating manual that the patient's occlusal plane be tipped slightly downward.

ANATOMIC STRUCTURES VISUALIZED ON A PANOREX RADIOGRAPH

One advantage of the Panorex radiograph is that it gives an overview of a much greater area than would be possible with an intraoral complete-mouth survey. Knight[37] and O'Carroll[38] enumerated the anatomic structures and artifacts visualized on a Panorex radiograph. Inherent artifacts are caused by the fact that the radiation passes through structures on the side not being radiographed before passing through structures on the side to be radiographed. This causes the radiographic shadow of structures from the opposite side to be projected onto the film.

Visceglia[39] identified the radiographic anatomy of a skull by use of Panorex radiography. He took serial Panorex radiographs of the individual bones of a skull. They were assembled in the same spatial relationship that a skull would occupy in taking a normal Panorex radiograph.

Tebo[40] described the pterygospinous bar which can be visualized on some Panorex radiographs and identified structures within the infratemporal fossa. Below is a list of the structures that have been identified on a normal Panorex radiograph.

Mandible

Mandibular condyle
Sigmoid notch
Coronoid process
Lower border of the mandible
Mandibular foramen
Mandibular canal
Submandibular fossa
Internal oblique ridge
External oblique ridge
Mylohyoid ridge
Mental foramen
Genial tubercles
Midline

Maxilla

Orbital cavity
Floor of the orbit
Nasal cavity
Conchae
Incisive foramen
Hard palate
Floor of the nose
Nasolacrimal duct
Infraorbital foramen
Maxillary sinus
Zygomatic process
Tuberosity

Temporal Bone

Upper surface of the zygomatic arch
Lower surface of the zygomatic arch
Roof of the infratemporal fossa
Styloid process
Articular eminence
Glenoid fossa
External auditory meatus
Mastoid process

Sphenoid Bone

Pterygomaxillary fissure
Lateral Pterygoid plate - medial boundary of the infratemporal fossa

Miscellaneous

Dorsum of tongue
Soft palate
Nasopharynx
Oropharynx
Ear lobe

ARTIFACTS VISIBLE ON A PANOREX RADIOGRAPH

Horizontal distortion on a Panorex radiograph is 6-17% with various head positions. Vertical distortion is fairly constant within the range of 10-14%. As teeth are moved further from the cassette the image is enlarged. Overlapping of proximal contacts is common, especially in the upper molar region. The upward tilt of the occlusal plane can cause loss of the TMJ and a blotting out of the apices of the maxillary teeth due to palatal vault superimposition. There is a clear central area due to automatic shut-off of the x-ray beam. The chin rest and its metal support are always projected. The images of the pancentric wings, although plastic, are visible when used. The shadow of the chin rest from the opposite side is invariably visible. The shadow of the lower border of the mandible from the opposite side is always evident. Any metal object the patient is wearing on the head or neck such as bobby pins, ear rings, hair clips, napkin chain, glasses, dental appliances, etc., will project as an artifact. Blurring due to patient movement is commonly visible. Blurring due to a double chair shift is rare. This defect may be corrected by using the reset button behind the chair and checking the plaque next to the chair for tube head position.

RADIATION IN PANOREX RADIOGRAPHY

A number of studies have investigated the amount of radiation produced by the Panorex and the area it covers. Hudson and Kumpula[41] in 1955, while developing the Panorex unit, tested the machine to determine radiation levels. Radiation levels at various points in and about the head were compared with those obtained while taking an extraoral complete-mouth series. A wax phantom head shaped over an adult skull was used. The wax was of tissue equivalent density and Syvert ionization chambers were used to measure the radiation. In all cases, levels of radiation with the Panorex radiograph were dramatically lower than with the complete-mouth fourteen film series. Radiation varied according to location, with the thyroid gland and neck receiving the highest amounts.

Kuba and Beck[42] in 1968 described a phantom used in research to establish the amount of radiation in Panorex radiography. The phantom consisted of a skull imbedded in plastic which had the same density as soft tissue. The phantom was sectioned transversely and the soft tissue equivalent of plastic was shaped like a head and torso.

Kuba and Beck[43,44] used the Average-Man Rhondo phantom to determine the general pattern of radiation distribution within the head. The Panorex used in their study did not cut off the radiation during chair shifting. The Average-Man Rhondo Phantom model was sectioned horizontally in layers about one inch thick. Between each pair of these layers a piece of radiographic film was placed, corresponding to the shape of the head.

Use of this film made it possible to determine the amounts of radiation by direct visual examination according to the density obtained. Triangularly shaped areas lateral to each center of rotation generally received less radiation and those anterior to the centers of rotation received the least radiation. Using the same phantom model, and calibrated ionization chambers, Kuba also determined the amount of radiation delivered to selected sites within the head, skin entrance dose, scatter and leakage radiation delivered to the male gonads and the operator. Highest levels of radiation were recorded at the centers of rotation, and skin lateral to the centers of rotation. The parotid gland was next in order. Their data do not substantiate claims that in using the Panorex, patients will receive approximately one-tenth the amount of radiation they would normally receive from a conventional intraoral complete-mouth series. In addition, their results do not support claims that actual radiation exposure is no greater than that involved in taking one intraoral film. Gonadal doses were extremely low, in the range of 0.01 milliroentgens. Due to the low gonadal dose, they concluded that a patient's gonadal region does not need to be protected with a lead apron. It is interesting that the gonads receive 0.125 roentgens per year from natural background radiation. The radiation exposure at the operator's position was 0.03 milliroentgen, which indicates that a person could take over 3000 Panorex films per week without exceeding the recommended limits of safety. This is calculated on a maximum permissible whole-body radiation dose of 100 milliroentgens per week for workers with ionizing radiations.

Jung[45] in 1965 examined gonadal doses resulting from Panorex radiographs and compared them to those obtained from 15 film x-ray examinations using Simplex Universal Dosimeters. Sixty-eight Panorex surveys were taken on an unidentified number of clinic patients. Comparisons were made to a separate group of patients who received thirty-four complete-mouth surveys. The Panorex radiograph gave approximately one-tenth as much radiation to the gonads as a conventional complete-mouth survey.

This figure, however, is misleading since additional aluminum filters were placed on surfaces of the Panorex x-ray tube head facing the patient.

Nelson and Rupp,[46] in a study of phantom depth dose distributions conducted at the U.S. Air Force School of Aerospace Medicine, found that distributions taken at identical KVP and MA settings on three different Panorex units varied widely. The results suggested that tube alignment was a critical factor and the most likely cause of this variability and the scattered values recorded in the dental literature.

Weissman and Longhurst[47] in 1972 compared the skin exposure and absorbed doses of Panorex radiography to selected sites in cadavers, adults and children with those obtained by other investigators. Their conclusions were that the wide variation in results described by other investigators,[40,41,44,48,65,66] was probably due to variations in the machines used, differences in dosimeter locations, and differences caused by use of a Rhondo phantom rather than a cadaver.

Jerman, Kinsley and Morris[48] in 1973 compared absorbed radiation from panoramic plus bitewing exposures to complete-mouth plus bitewing exposures in eight adult patients. They used dosimeters implanted in maxillary and mandibular mouth guards to measure the absorbed dose. In addition, dosimeters were placed over the thyroid, each mastoid process, cheek and eyelid.. They found that Panorex plus posterior bitewings exposed the patient to 82% less radiation than the complete-mouth survey plus posterior bitewings.

IMAGE DISTORTION IN PANOREX RADIOGRAPHY

There is magnification in the Panorex technique because the film is placed in a cassette away from the patient's head. Contributing to this is the fact that the focal trough is U-shaped and extends posteriorly in a straight line and then actually points in, toward the midline, in the extreme posterior regions opposite to the direction of the ramus of the mandible. The further the patient's jaw deviates from that of the average patient to whom the focal trough is made to conform, the more the image is distorted.

Kite and associates[49] in 1962 were first to investigate image distortion in the Panorex. They analyzed the degree of image distortion by a series of measurements on three groups of films. The first group included the image of a wire screen with the contour of the mandible which was measured. Similar measurements were then made on a human skull. A series of clinical Panorex radiographs was also taken and compared to two wires calibrated at one centimeter intervals that had been placed on the maxillary and mandibular alveolar mucosa from second molar to second molar. It was concluded that negative as well as positive horizontal distortion and image size were produced by the Panorex. Clinically, the inherent or intrinsic image distortion can be exaggerated in three ways: if the patient's head is improperly positioned during exposure, if there are differences in width and symmetry of the jaws being examined, and if the subject moves during exposure. These investigators determined that with the screen properly placed in the machine, the right molar segment produced horizontal image distortion of about 6%. If the screen was moved half a centimeter to the left, the image was enlarged horizontally by 17%. The greatest distortion was found to be a positive enlargement in the permanent molar regions. This is in contrast to the less than one-to-one ratio found in the region of the anterior teeth.

Yamane and Biewald[50] determined how accurately the Panorex could reproduce a variety of simulated jaw sizes and shapes. They used a one millimeter wire bent to simulate a mandibular arch with half millimeter wire posts soldered perpendicular to the wire and corresponding to the locations of the teeth. To determine the influence of jaw width on image distortion, the distance between the terminal ends of the wire was progressively increased by one centimeter increments with each successive exposure. To determine whether the accuracy of the image reproduction would be affected by the position of the mandible, the locations of the wire on the chin rest were altered. The percentage distortion was calculated by measuring the distances between the posts on the wire and the image of the posts on the film. As the distance between the terminal ends of the wire (the bigonial width) increased, the area representing the location of the first molar tooth had the greatest distortion. The largest variation in the percentage distortion was at the approximate location of the third molar tooth. As the wire was moved posteriorly on the chin rest, the percentage distortion fluctuated considerably in the area corresponding to the location of the first molar teeth. Fluctuation in image distortion also existed with repeated exposure of the wire when it was kept at the same location on the chin rest.

Brueggmann[51] in 1967 measured the vertical distortion on processed Panorex film using short lengths of 0.35 gauge wire in a dry skull and wax bite model. Vertical distortion remained fairly constant but horizontal distortion varied greatly depending on jaw location. He found an increase in positive distortion in the molar regions.

Christen and Segreto[52] in 1968 used dry intact human skulls that were tagged with various metallic markers and outlined normal anatomic structures. Orthodontic wire (0.50 inch) was cut into 2.5 centimeter sections, notched in the center, and formed into crosses. These markers were taped on the maxilla and mandible to study vertical and horizontal distortions in the bicuspid, molar and ramus regions. The cross markers were placed in three planes in relation to the teeth — buccally, lingually and in the same plane as the long axis of the teeth. Stainless steel ball bearings (6.5 to 9.5 millimeters in diameter) were taped to the dry skulls and radiographed. The use of these metallic marking devices made it possible to show that vertical enlargement of the pins could range from 10 to 14% in normal head position and could vary even more when the head was placed eccentrically. Frontal compression of the pins and steel bearings could be as large as 34% with eccentric head positioning. Even slight variations in head placement could produce considerable distortion, especially in the ramus region, coronoid process and condyles. In normal Panorex projections teeth were lengthened vertically and shortened horizontally.

Diers[53] in 1971 determined the mesio-distal diameters of posterior teeth from sixteen human skulls. He measured the posterior teeth on a Panorex radiograph of each skull and compared these measurements to the actual mesio-distal dimensions of each tooth taken directly from their respective skulls. There was both negative and positive distortion on the Panorex radiograph. The percent of distortion in the mandible ranged from -4.7% in the cuspid region to 32.9% in the second molar region. Percentage distortion in the maxilla was -4.1% in the cuspid region and 20.3% in the second molar region.

Schneider[54] in 1972 attempted to predict the mesial-distal dimensions of teeth with panoramic radiography. His cross sectional study included a randomly selected sample of 50 children, ages 6 to 11 years, equally divided according to age and sex. The mesial-distal dimensions of the cuspid and bicuspid teeth as measured from periapical and occlusal radiographs, standard Panorex radiographs, quadrant totals from Moyer's mathematical charts, and the experimental Panorex method were compared statistically.

In the experimental method, using the Panorex radiograph, the head was rotated approximately 28^{o} and the patient was asked to bite on a plastic template. The quadrants filmed were thus brought closer to the film and more nearly within the focal trough. A separate Panorex was taken for each half of the face with the patient positioned eccentrically for each side.

In this study the images of the teeth with the standard Panorex showed considerable distortion. Horizontal distortion of 24.3% was noted in the bicuspid area. In contrast, 0.9% to 6.8% distortion occurred in the bicuspid region with the Panorex in which the experimental method was used.

Brown, Christen, and Jerman[55] in 1972 studied the dimension of the focal trough in Panorex radiography. The area of focus of the Panorex radiograph was determined in three dimensions. As expected, the area of focus was U-shaped but wider than previously described. Other investigators had calculated the focal trough to be one-half to three-quarters of an inch wide (1.3 to 1.9 centimeters). This investigation found the area of the focal trough to be approximately 1.4 to 2.4 centimeters wide. The area of focus extended posteriorly in a straight line and then pointed in toward the midline in the extreme posterior regions, opposite to the direction of the ramus of the mandible. The focal trough extended in a plane 22 to 82 millimeters vertically, superior to the chin rest.

ADVANTAGES AND DISADVANTAGES (LIMITATIONS) OF PANOREX RADIOGRAPHY

Many authors have written about the advantages of Panorex radiography.[56-68] Others have described the limitations of Panorex radiography.[36,51,69-73]

Advantages of Panorex radiography are as follows:

Efficiency in patient positioning, film placement, developing and mounting make it a good time-saver as compared to a complete-mouth 14 film survey. A study at the University of Missouri reported that 10.38 minutes was saved in taking a Panorex as compared to a complete-mouth intraoral survey.[71]

Patient comfort is improved since the technique is extraoral and eliminates problems in film placement such as shallow palatal vaults, maxillary or mandibular tori, or minimal muscle attachments.

Patient acceptance is especially good in the pedodontic age group or in patients who have physical or mental handicaps. In addition, it eliminates problems with gagging or trismus.

Economics is a consideration. Retakes, which are commonly necessary in obtaining a complete-mouth survey, are seldom needed with the Panorex. There is a 50% reduction in the cost since only one radiograph is required with the Panorex in comparison to the 14 to 16 individually wrapped radiographs required for a complete-mouth survey. Also, as has already been mentioned, considerably less time is required.

Radiation levels are lower to the patient as well as the operator compared to a complete-mouth series. Finally, the most obvious advantage is the scope of the examination. The large area surveyed by the Panorex radiograph makes it invaluable as a screening examination. Its operation is straightforward and the basic procedure can be learned in half an hour.

Typical of the surveys made are those conducted by the American Dental Association Health Evaluation Program at each annual session beginning in 1965. From that year to 1969 more than 1000 dentists were surveyed each year and findings of interest on the radiographs were noted and tabulated.[74-77] Other studies by the Air

Force,[78] Veterans Administration,[79] and Canadian Armed Forces[80] have all demonstrated similar findings.

Disadvantages of the technique include the fact that the initial cost of the machine is substantial, being in the neighborhood of $7,000. The space requirements for the Panorex are greater than for a conventional x-ray machine. Also, it would be needed in addition to the regular x-ray machine, not as a substitute for it.

Image distortion is more evident in the Panorex than in intra-oral periapical or bitewing radiographs. There are overlapped contacts and magnification, especially in the maxillary bicuspid area. Compared to a periapical or bitewing radiograph, image definition and detail are poor, due to the use of intensifying screens, faster film, increased object film distance, and movement of the x-ray tube and film. Incipient carious lesions are more easily missed and crestal bone patterns are less definite. One final disadvantage would be that head position is very critical to obtaining a good projection. If the patient's head is not positioned ideally, there is loss of the TMJ structures, superimposition of the palate on the apices of the maxillary teeth and an increase in magnification and distortion. At times a patient with an unusually large head or short neck will be difficult to position. The cassette holder will either move the head or strike the shoulder while being lowered to position. In either instance a compromise position of head or cassette holder is necessary, which will result in a less than ideal Panorex radiograph.

SPECIFIC CLINICAL USES OF PANOREX RADIOGRAPHY

Numerous authors have discussed the use of Panorex radiography in specialty areas of dentistry. Laney and Tolman[81] described its use by the oral surgeon, periodontist, prosthodontist, pedodontist, and orthodontist to help screen for pathologic processes. Thorpe[82] delineated uses of the Panorex in visualizing problems involved in oral pathology, prosthetics, and growth and development.

Specifically, Rothstein[83] described the findings on Panorex radiographs of patients with a variety of metabolic bone diseases including acromegaly, Pagent's disease of bone, and hyperparathyroidism. Rhoades and Scott[84] described the use of Panorex radiography in the diagnosis of salivary stones, cysts of the coronoid process, carcinoma in the maxillary sinus, multiple facial fractures and in the diagnosis of supernumerary teeth. Shramek and Rappaport[85] discussed its use in the screening and early detection of maxillary sinus malignancy. They stated that antral carcinoma can be detected by using a Panorex in a normal position and by lifting the machine to take a special "sinus view". Use of the Panorex is suggested both as a screening device for maxillary sinus pathology and as a guide for surgical planning.

Pfeifer and Dean[86] discussed shortcomings of the Panorex radiograph in periodontal diagnosis. They pointed out that there was elongation of the teeth, the alveolar crest appeared flattened, the lamina dura was not easily followed, and calculus deposits frequently did not appear.

Smylski[87] explained how panoramic radiography is used in oral surgery. He noted that impacted teeth are included in their entirety, and observed in a truer position. Root remnants, pathologic conditions, extent and displacement of fractures are easily viewed. It can also be used in patients with trismus and for patient education.

Pappas and Wallace[88] used panoramic radiographs in sialography. They demonstrated an alternate head position 20 to 30 degrees to one side which helped bring the glands to a position within the focal trough of the machine. This allowed a better view of the sialogram. Updegrave[89] has described the use of alternate head positions to view the mandibular ramus in Panorex radiography. These alternate head positions bring the ramus, condyle and coronoid process into the focal trough so that a sharper, truer picture of these structures can be seen, The modified positions provide an excellent radiograph, if a fracture of the ramus or condyle is suspected. This special projection does not allow visualization of structures anterior to the ramus.

One common objection to the Panorex radiograph is the overlapping or duplication of structures on each side of the film in the anterior area. However, Turk and Katzenell[90] described how a Panorex radiograph can be used to locate foreign objects in the anterior part of the mandible or maxilla. The permanent anterior teeth are used as the static reference point and the buccal object rule of radiography is applied. The relative movement of the foreign object in relation to the anterior teeth is noted. Should the impacted tooth or foreign body move in the same direction as the radiation source, it is located closer to the source of radiation than the reference point and, therefore, lingually impacted. If the impaction or foreign object moves in a direction opposite that of the radiation source, it is located farther from the source than the reference teeth and its location is on the labial side.

USE OF PANORAMIC RADIOGRAPHY IN ORTHODONTIC DIAGNOSIS

Conley[91] described a technique for studying the spatial relationships of oral hard tissues using Panorex radiography. The technique included the utilization of a positioning device or cephalostat and specific anatomic landmarks. It provided a method of positively positioning a patient for subsequent panoral radiographs. Although considerable distortion was present on each film, the distortion was reproducible segmentally and quadrant superimpositioning was therefore possible. Linear quantification of a given individual was possible in vertical and horizontal planes found within the boundaries of the panoral radiograph. Conley concluded that the investigation provided a scientific method for documenting radiographically the amount and direction of growth, and changes in position of the hard tissues of the oral region due to growth.

Graber[92] described the use of the Panorex in growth and development to diagnose abnormal eruptions, impactions, cysts, neoplasms, supernumerary teeth, congenital absence of teeth, premature loss, prolonged retention, abnormal resorption, ankylosis, TMJ disturbances, fractures, and resections. In space inadequacy and serial extraction procedures it was an aid in early recognition of arch length deficiency and proper individual differential diagnosis. It was useful in pre-treatment, treatment, and post-treatment progress appraisal. Viewing the Panorex and the growth and development of the patient was helpful in deciding when and how to institute active orthodontic treatment. Serial radiographs on routine adjustment visits permitted the orthodontist to see the changing relationships of the clinical crowns.

Graber cited the continuing assessment of tissue response or lack of response, periodontal membrane thickness, paralleling roots next to extraction sites, tooth tipping, alveolar crest damage, and carious lesions in unbanded teeth as examples of information that can be derived from the Panorex and applied to orthodontic treatment.

Hauck[93] documented tooth movement by means of panoral radiography. Cuspid retractions were followed over a ten-month period. Superimposed Panorex radiograph tracings were accomplished by reproducing patient positioning using a cephalostat. "Because of variable distortion it was not feasible to develop a composite tracing over the total area of the panoral radiograph taken in a longitudinal series. Fortunately, it was readily possible to accurately superimpose the tracing upon each individual quadrant of the dental arch in the radiograph."[93]

Diers[53] studied the Panorex for the interpretation of the mesio-distal axial inclinations and mesio-distal diameters of the posterior teeth on sixteen adult human skulls. A series of means and standard deviations for each posterior tooth interpreted by the Panorex was developed. Individual measurements of posterior teeth as seen on the Panorex were related and compared to these standards for use in diagnosis, treatment and evaluation of orthodontic cases. Diers concluded that if these measurements were to be used for arch length analysis, further research was necessary. Accurate interpretation of the mesio-distal diameters of the posterior teeth as seen on the Panorex radiograph was not possible in this investigation.

Schneider[54] determined the relative accuracy of a Panorex radiograph in the determination of unerupted tooth mass. Diameters of the unerupted permanent cuspids and bicuspids for each of a group of 50 children were measured to assess the degree of linear distortion between the Panorex radiograph and three other types of radiographic films. A number of experimental Panorex films were made with the patient positioned eccentrically. Although magnification was reduced considerably, the experimental technique was not considered to be of sufficient and consistent accuracy to be applicable in the determination of tooth mass for the mixed dentition analysis.

Rosenberg and Law[94] also attempted to use Panorex radiography in dental arch space analysis. Correction equations were developed for the purpose of establishing a clinically accurate method for space analysis. The sample included 71 patients between the ages of 10 and 16 years on which Panorex radiographs and models were taken. Measurements from the models were compared to those on the Panorex radiographs. Distortions were statistically significant and each of the teeth required its own regression or prediction equation. This meant that distortions for each tooth type were different. Rosenberg also found that distortions between the left and right sides were statistically significant. The results indicated that the panoramic approach to space analysis was less accurate than other accepted methods. It was noted that the experimental method might have benefited by the development and use of a special head holder and a standardized head positioning procedure.

CEPHALOSTATS USED IN PANOREX RADIOGRAPHY

Three types of cephalostats have been used with the Panorex machine. One is the Pancentric Head Positioner, produced by the S.S. White Company and furnished with the machine. It has two purposes. By use of the plastic wings it measures the width of the head to determine the correct KVP setting. It also has a set screw so that the wings can be tightened onto a head laterally and thus along with the chin rest aid in holding the head rigid during the panoramic exposure. Exact duplication of head position is not possible with this apparatus. This cephalostat was developed by Kane[95] and modified by the S.S. White Company into their present head positioner.

Hymer[96] in 1965 developed a cephalostat for the Panorex (Figure 11). The cephalostat was machined from a variety of metals. Because of its low density, magnesium was used for portions of the apparatus lying in the path of the x-ray beam. Plexiglas was substituted for magnesium in areas where the magnesium would produce an objectionable shadow. Millimeter scales were added for the purpose of returning the cephalostat to a previously recorded setting. The head was oriented in the cephalostat by using porion and nasion as reference points. A Plexiglas bite fork with metal implants was used to stabilize the occlusal plane. Five subjects were selected for trial of the cephalostat. Two subjects were used as controls in evaluating within-operator and between-operator variations in repositioning the subject to either machine or anatomic landmarks. Each of the two subjects was positioned with the cephalostat and settings recorded. Two Panorex radiographs were taken of each subject. The patient was not repositioned between exposures. In this instance the entire radiograph was superimposed without visible discrepancy in either the metallic implants or anatomic structures.

In a second procedure each of three subjects was positioned on the Panorex with the cephalostat and settings recorded. After one radiograph was taken, the subject was removed and all settings changed. The subject was then repositioned by the same operator to the previously recorded settings and a second Panorex radiograph was taken. The repositioning was done a second time exactly as before, but by a different operator, and a third Panorex radiograph was obtained. In serial radiographs of the subject by the same operator, superimpositioning upon anatomical landmarks was without visible discrepancy in one subject only. In the remaining two subjects the visible discrepancy between concordance of anatomical landmarks and metallic implant images was within 2 millimeters. In testing between operator variation, using the same subjects, concordance between anatomic landmarks and metallic implant images was less than that observed in the within-operator study. In one subject, visible discrepancy reached approximately 4 millimeters.

The apparatus provided a method of producing serial Panorex radiographs which the author stated could be used in the study of morphological and spatial changes in the hard tissues within the oral region. "Limited testing demonstrated the range of variability in producing serial radiographs with this procedure to be comparable to or within closer tolerances than those currently accepted in conventional radiographic cephalometry."[96, 8] The positioning device proved to be accurate enough to position the patient for serial studies when anatomic landmarks were used for the superimpositioning of serial radiographs.

Ryan, Rosenberg and Law[97] in 1973 evaluated the effectiveness of the S.S. White Pancentric Head Positioner in use with Panorex radiography. Forty subjects from 10 to 26 years of age were selected, all of whom had fully erupted permanent bicuspids and cuspids. Panorex radiographs were taken by two dental assistants trained in the procedure. Heads of the subjects were stabilized using the Pancentric Head Positioner. The greatest mesio-distal widths of the twelve cuspid and bicuspid teeth of each of the forty patients were measured to the nearest tenth of a millimeter with a Boley gauge. Each tooth was measured on the Panorex radiograph and compared to a measurement of the same tooth taken either intraorally or from a study cast.

Data from this study were evaluated statistically. A statistical comparison was also made between these data and the data collected by Rosenberg and Law[94] in a similar study using the same Panorex machine but not making use of the head positioner.

Image size distortions were statistically significant, even when the Pancentric Head Positioner was used. Since distortion for each tooth type was different, each required its own regression equation. Differences between left and right sides were not statistically significant. The major contribution of the head positioner was the reduction in the variability of the distortions. If this technique were used for space analysis,regression equations would have to be determined for each individual Panorex machine and head positioner.

The survey of the literature demonstrates that no one has taken hard tissue measurements, either angular or linear on a Panorex and attempted to use them in evaluating growth and development (a static analysis) of a child.

METHODS AND MATERIALS

A pilot study was performed on a dried skull to identify selected skeletal landmarks on Panorex radiographs. Using these landmarks, measurements of bony relationships of the head were completed. The values obtained on a lateral headplate were compared with measurements on the same patient's Panorex radiograph for a group of forty-eight children.

Pilot Study

The following structures relevant to the clinical phase of the study were located on a child's dry skull and labeled with radiopaque markers.

*1. External auditory meatus
*2. Pterygomaxillary fissure
3. Nasal cavity
*4. Inferior orbital rim
5. Nasal septum
6. Maxillary midline
7. Mandibular midline
8. Genial tubercle
9. Infraorbital foramen
*10. Nasal spine
11. Anterior palatine foramen
12. Mandibular foramen
13. Mental foramen
14. Midline inferior border of mandible
15. Maxillary tuberosity
*16. Zygomatic arch
17. Glenoid fossa
18. Articular eminence

The structures marked with asterisks are used routinely in cephalometric analysis. Once a structure was located on the dry skull, a radiopaque marker such as a paper clip wire, lead foil strip, or BB shot was used to identify it on the radiograph (Figure 12). The radiopaque markers were held in place by small strips of masking tape. Next, the skull was placed on a clear Plexiglas support which was attached by means of small "C" clamps to the chin rest of the Panorex unit. The position of the dry skull was similar to the usual head position of a patient being radiographed (Figure 13).

The scale on the chin rest support was set at 3-1/2 and the cassette holder lowered to 3-1/4 on its scale, located on the back support column of the Panorex. A standard pan-o-screen was used. The cassette was loaded using Kodak Blue Brand 5 X 12 inch BB 54 film. Radiographs were developed in the Indiana University School of Dentistry Department of Radiology. At a temperature of 68°F, the developing sequence included three minutes in the developer, a rinse in water, three minutes in the fixer, and a final rinse in water before being dried.

Since the skull lacked soft tissue, it was not possible to determine bizygomatic width by the usual measurement. Therefore, a series of Panorex radiographs were taken at 5 KVP intervals between 55 and 90 KVP and at 5 MA. The various combinations of exposures were recorded and the radiographs were developed and compared. The exposure having the best density and contrast was at 75 KVP and 5 MA. All subsequent skull radiographs were taken at these settings.

A Panorex radiograph of the skull with no radiopaque markers on it was taken. After it was developed and dried, a large piece of acetate tracing paper was cut to size and placed over whichever half of the radiograph demonstrated the least distortion as determined visually by the author. If both halves of the radiograph appeared equally acceptable, the patient's left side was selected. Strips of masking tape were placed over the top to hold the tracing paper in place. A #3 sharp lead pencil was used to make a tracing of the Panorex radiograph. By comparing the tracing of the Panorex radiograph without the radiopaque markers with the Panorex with radiopaque markers, cephalometric landmarks were verified for the tracing and the following panoramic landmarks as defined by the author were used.

1. Nasal cavity (NC) - An area bounded by the lateral walls of the nasal cavity. A line is drawn perpendicular to Frankfort horizontal and splitting the distance between the walls of the opening.
2. Posterior Condylion (PC) - A point depicting the most convex portion of the posterior aspect of the mandibular condyle.
3. Articulare (Ar) - The point where a straight line drawn along the posterior edge of the ramus extending to condylion crosses Frankfort horizontal.
4. Frankfort horizontal (FH) - A straight line drawn from the most superior point of the external auditory meatus to the inferior rim of the orbit.
5. Pterygomaxillary fissure (Ptm) - An area bounded posteriorly by the anterior border of the lateral pterygoid plate and anteriorly by the posterior surface of the maxilla, leading down toward the maxillary tuberosity.
6. Posterior nasal spine (PNS) - The posterior limit of the maxilla. Determined by dropping a line down through Ptm perpendicular to Frankfort horizontal. PNS is where this line crosses a line representing nasal floor.
7. Anterior nasal spine (ANS) - Where the line representing nasal floor intersects a line extending down from the center of the nasal cavity, perpendicular to Frankfort horizontal.

8. Gnathion (Gn) - A point marking where a line drawn perpendicular to Frankfort horizontal and centered in nasal cavity crosses the lower border of the mandible.
9. Gonion (Go) - A point marking where the ramus of the mandible begins and where the body of the mandible ends. It is the point where mandibular plane intersects the line drawn along the posterior edge of the ramus to condylion.
10. Incision superious (I_s) - The incisal edge of the upper central incisor.
11. Nasal floor (NF) - A line made by splitting the distance between the true nasal floor and the roof of the mouth.
12. Mandibular plane (MP) - A line drawn tangent to the lower border of the mandible.
13. Occlusal plane (OP) - A line drawn parallel to the line of occlusion of the posterior teeth.
14. Nasion (N) - A point established by marking the vertical center of the nasion support.
15. Genial tubercle (GT) - A point on the mandible signifying the center of the genial tubercle.

The following angular or linear measurements were developed using the above landmarks.

1.	Length of posterior cranial base	Ar-Ptm (FH)
2.	Length of body of the maxilla	PNS-ANS (FH)
3.	Effective length of mandible	PC-Gn (FH)
4.	Absolute length of mandible	PC-Gn
5.	Length of mandibular ramus	Go-PC
6.	Length of mandibular body	Gn-Go
7.	Gonial angle	Ar-Go-MP angular
8.	Upper facial height	N-ANS ($\perp$FH)

9.	Lower facial height	ANS-Gn ($\perp$FH)
10	Nasal floor to Frankfort horizontal	NF-FH angular
11.	Mandibular plane to Frankfort horizontal	MP-FH angular
12	Angle of convexity	NC-Gn-GT angular
13.	Ramal plane angle	Go-Ar-FH angular
14.	Occlusal plane angle	OP-FH angular
15.	Vertical position of upper incisor	ANS-I_s ($\perp$FH)

Linear measurements, to the nearest tenth of a millimeter, were determined by placing a sheet of millimeter ruled graph paper under the tracing paper. Angular measurements were recorded to the nearest tenth of a degree using a protractor.

Clinical Study

Panorex radiographs and lateral cephalometric headplates were obtained and evaluated on forty-eight patients selected from the Indiana University School of Dentistry Division of Graduate Pedodontics. Subjects were Caucasoid, ages 5 to 10 years, and evenly distributed according to age and sex.

Panorex radiographs were taken in the Indiana University School of Dentistry Division of Graduate Pedodontics, on an S.S. White Panorex model #PAN-3H, using the procedure outlined in the S.S. White Panorex Operation Manual.[35] The only change in the procedure was the use of ear rods and a nasion support to stabilize the patient's head after the correct head position had been established (Figures 14 and 15). Vertical and horizontal settings on the ear rod holders and nasion support were recorded for each patient. This allowed a duplicate Panorex radiograph to be taken of any patient on a subsequent visit using the previously recorded settings on the cephalostat to reposition the head. Measurements from tracings of the two Panorex radiographs were then compared to determine if exact head positions could be duplicated. This second Panorex radiograph was taken on a series of eight patients.

Super pan-o-screen cassettes and Kodak 5 X 12 inch panoramic dental single coated blue sensitive DF-85 film were used. Panorex radiographs were developed in an S.S. White Auveloper model #2459 according to the manufacturer's instructions.

A lateral cephalometric radiograph of each subject was obtained. The radiographs were taken in the Indiana University School of Dentistry Department of Orthodontics. A Broadbent-Bolton roentgenographic cephalometer was used with the technique developed by Broadbent. Cassettes were loaded with Kodak 8 X 10 inch RP/L54 film. Radiographs were developed in a Profexray x-ray film processor.

An 8 X 10 inch piece of acetate tracing paper was placed over the cephalometric radiograph and held in place with black masking tape. A #3 lead pencil was used to make a tracing of the radiograph, using accepted cephalometric landmarks (Figure 16). Landmarks were selected so that measurements comparable to those taken on the Panorex radiograph could be obtained from the lateral headplate. This enabled the same angular and linear measurements enumerated on the previous page to be made on the lateral headplate. Landmarks were the same as those used by the Indiana University School of Dentistry Department of Orthodontics.

All radiographs were taken and traced by the investigator. Measurements determined in the pilot study on the Panorex radiographs were performed twice, once by each of two evaluators, on each of forty-eight Panorex radiographs and lateral headplates (Figure 17). A reference point guide was furnished to each evaluator. Each evaluator recorded his findings on a separate form to aid in eliminating examiner bias (Figure 18). An average of the two evaluators'measurements was used as the definitive value. During the training session for the evaluators each measurement was explained and a trial set of measurements was taken by each evaluator on a lateral headplate and a Panorex radiograph. Measurements were evaluated and adjustments made to ensure that comparable measuring techniques were performed.

To assess the reproducibility of the Panorex tracings a second tracing and set of measurements were performed on eight of the study sample. The second measurements were compared to those taken from the initial tracing. In performing the second set of measurements,the examiner did not know whose Panorex tracing he was evaluating.

RESULTS

The data were transferred to standard IBM punch cards and submitted for statistical analysis to the Research Computation Center of Indiana University-Purdue University, Indianapolis, Indiana. All of the raw data were key punched and verified, including measurements of both evaluator one and two in addition to the average measurements. Each of the six columns of figures on each patient was placed on a separate punch card. This resulted in a total of 288 cards which were divided into two groups, one containing the data from evaluators one and two and the other containing the averages. Numbers on the raw data cards were carried to the first decimal place but computer print-outs were rounded off to the second decimal place to allow better evaluation of the first decimal place. Cards were identified by the first three digits on the left, which identified age, sex, and column number in that order. Most of the tables were compiled from data in the computer print-outs although computations for data in Tables VIII and IX were performed by hand.

Measurements performed by evaluators one and two on each technique were compared using the Newman-Keul t test to determine if a significant difference existed between evaluators (Table I). The mean measurements between evaluators in each technique compared in all but one instance to within .2 mm. In the one exception the comparison differed by only .6 mm. This close comparison was accepted as sufficient evidence that a significant difference could not be demonstrated between the two evaluators; thus the averages of the two evaluators' measurements were used in computing the rest of the statistical analysis.

To determine whether a close relationship existed between similar measurements on each technique, a comparison of the lateral headplate and Panorex measurements across the fifteen variables was made using paired observations. This particular t test is used to compare two sets of matched categorized observations for the presence of a significant difference (Table II). With 47 degrees of freedom (DF) and a critical value of t being 2.01 at the .01 level of significance, differences were noted between all but three of the variables. Those measurements between which a significant difference was not demonstrated were nasal floor to Frankfort horizontal, angle of convexity, and occlusal plane angle. This confirmed that the Panorex technique and the lateral headplate technique are two almost completely separate procedures and cannot be used interchangeably for purposes of patient evaluation.

A comparison of the means for each pair of variables in Table II demonstrated that all but one of the Panorex linear measurements showed a positive enlargement or distortion when compared to the lateral headplate. The enlargement ranged from 19 to 35 per cent. Conversely, of the angular mean measurement comparisons, all but one angle showed a negative distortion. Thus the angles from the Panorex were smaller than their lateral headplate counterparts in a range of from 4 to 65 percent.

To evaluate the effect that differences in the sex of the patients had on the comparison of the measurements, the data were separated into male and female samples and resubmitted for evaluation. Comparisons were made across the fifteen variables, as before, using paired observations for each sample. With 23 degrees of freedom (DF) the critical value of t was 2.07 at the .01 level of significance. Within the male sample all but four values of t were significant (Table III). The values of t in which a significant difference was not revealed included the mean measurements for nasal floor to Frankfort horizontal, angle of convexity, occlusal plane angle and ramal plane angle. The female sample resulted in all but three values of t being significant (Table IV). The three values of t for which significant differences were not demonstrated were for nasal floor to Frankfort horizontal, angle of convexity, and occlusal plane. Although a slight difference in the t values was noted, the change was not enough to support the premise that differences in the patients' sex had any effect on the comparison between the two techniques.

Lateral headplate and Panorex mean measurements were divided by age and technique to compare changes in the measurements with age (Tables V and VI). With the exception of the measurements for the ten-year-olds, who tended to have some of the lowest measurement values, the other measurements between age groups in both techniques generally increased or decreased with age but not significantly so.

Measurements from the lateral headplate and Panorex tracings were compared to see whether there was correlation of any kind in or between the two groups of data. A Pearson r value of correlation coefficient was determined between every mean measurement and all other mean measurements. The resulting data were printed as a matrix of correlation coefficients (Table VII). Numbers 1-15 down and across refer to measurement correlations from the lateral headplate and numbers 16-30 down and across refer to measurement correlations from the Panorex. Any combination of numbers 1-15 across and numbers 16 - 30 down are correlation coefficients comparing lateral headplate mean measurements to Panorex mean measurements.

Pearson r value correlation coefficient for 48 subjects using a two tail test was significant at $r = \pm .28$ at the .05 level of significance. At this level of significance there is a fit between many of the within and between technique correlations. However, for purposes of this study the lowest acceptable level of correlation was $\pm .71$. This level of correlation was found only twice in the comparison of lateral headplate to Panorex. Negative numbers indicate that one measurement enlarged as the other become smaller or vice versa. An inverse relationship thus existed between the measurements. Although correlation between techniques was not proven to be significantly similar to allow one to be interchanged for the other, the following conclusions can be drawn from the correlations. The Panorex mean measurements showed as much within technique correlation as did the lateral headplate mean measurements. The highest correlations between the two techniques should have been found when similar measurements from each technique were compared. All of these measurements except those for nasal floor to Frankfort horizontal and angle of convexity showed a significant correlation. Between the techniques there is a significant correlation but not a linear one. However, in all but one instance, the correlations are not above the ± .71 level considered significant for purposes of patient evaluation. The one measurement which showed a good correlation was gonial angle at an r value of .79.

To evaluate the effect that tracing error may have had on the study, Spearman Rho rank order correlation was established comparing measurements from duplicate tracings of Panorex radiographs to the original tracing by the same evaluator (Table VIII). The ρ value of at least .71 at the .001 level of significance was considered desirable but was attained in only nine of the fifteen measurements. Thus, excluding the measurement nasal floor to Frankfort horizontal, a significant difference between the duplicate tracings was not demonstrated.

The ability of the cephalostat used in the study to reproduce the same head position more than once was evaluated. Spearman Rho rank order correlation of measurements from tracings of eight duplicate pairs of Panorex radiographs was undertaken. All but four values of ρ were above ± .47 at the .05 level of significance. Only half of the values of rho were above the ±.71 level of significance considered acceptable for clinical purposes. This indicated that the cephalostat was questionable in its ability to reliably reproduce the same head position.

FIGURES

Figure 1. Flat plane laminagraph. An x-ray beam having an axis of rotation at point A is projected through a mass of tissue. The film is at a predetermined position and is made to move so that the image of point A is projected on the same spot on the film when the x-ray source moves from T_1 to T_2. Under these circumstances, all points on plane A are similarly cast in a constant position on the film. All points in the tissue not on plane A (represented by X and Y) are distorted; because of the geometry involved, it is impossible for other points to be cast in a constant position on the x-ray film.[16]

T—X-ray tube (moves from T_1 to T_2)
A—Point on Plane A selected for examination
X and Y—Points not on plane of examination
FP—Film position (moves from FP_1 to FP_2)
FM—Distance of film movement
T_1A to T_2A—
Projection of point A at two tube/film positions
T_1X to T_2X—
Projection of point X at two tube/film positions

Under the selected conditions of tube movement, film movement, tube to plane and plane to film distances:
T_1A to T_2A = FM
T_1X to $T_2V \neq$ FM

Thus: Definition of point A is maintained while points X and Y become blurred.

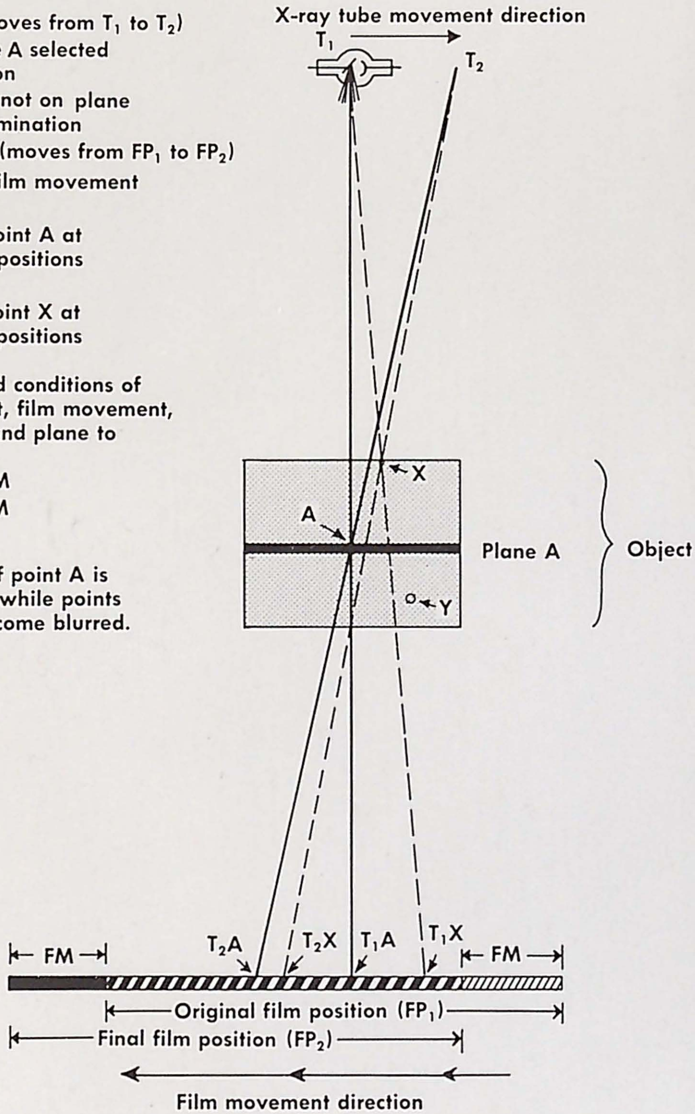


Figure 2. Diagrams demonstrating the relative movement of the radiation source and film in the panoramic machine described by Nelson and Kumpula.[21]

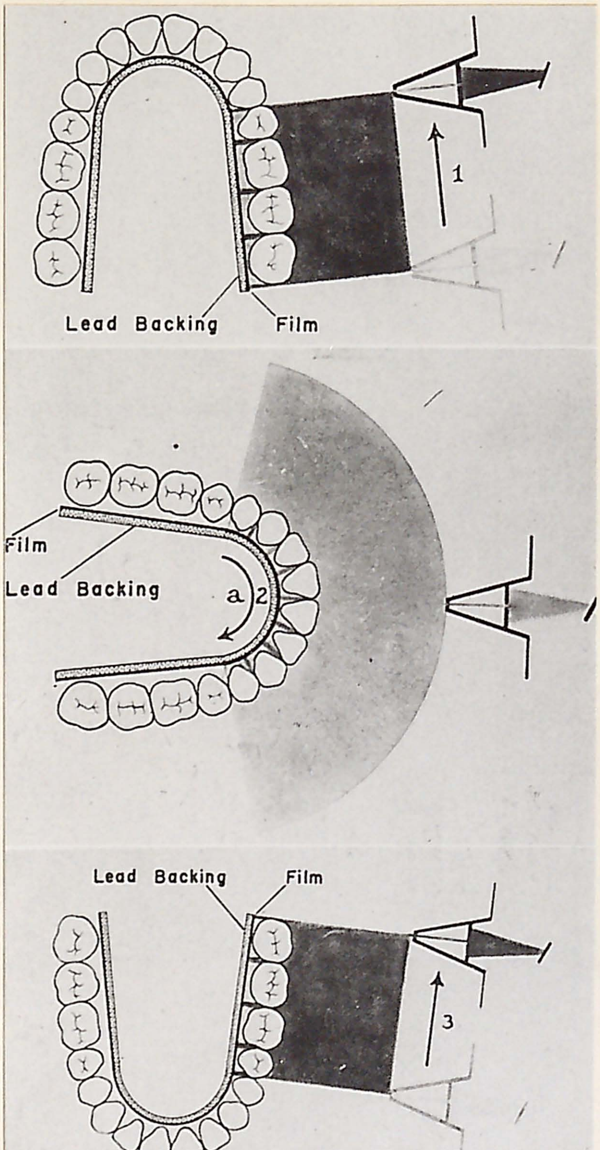
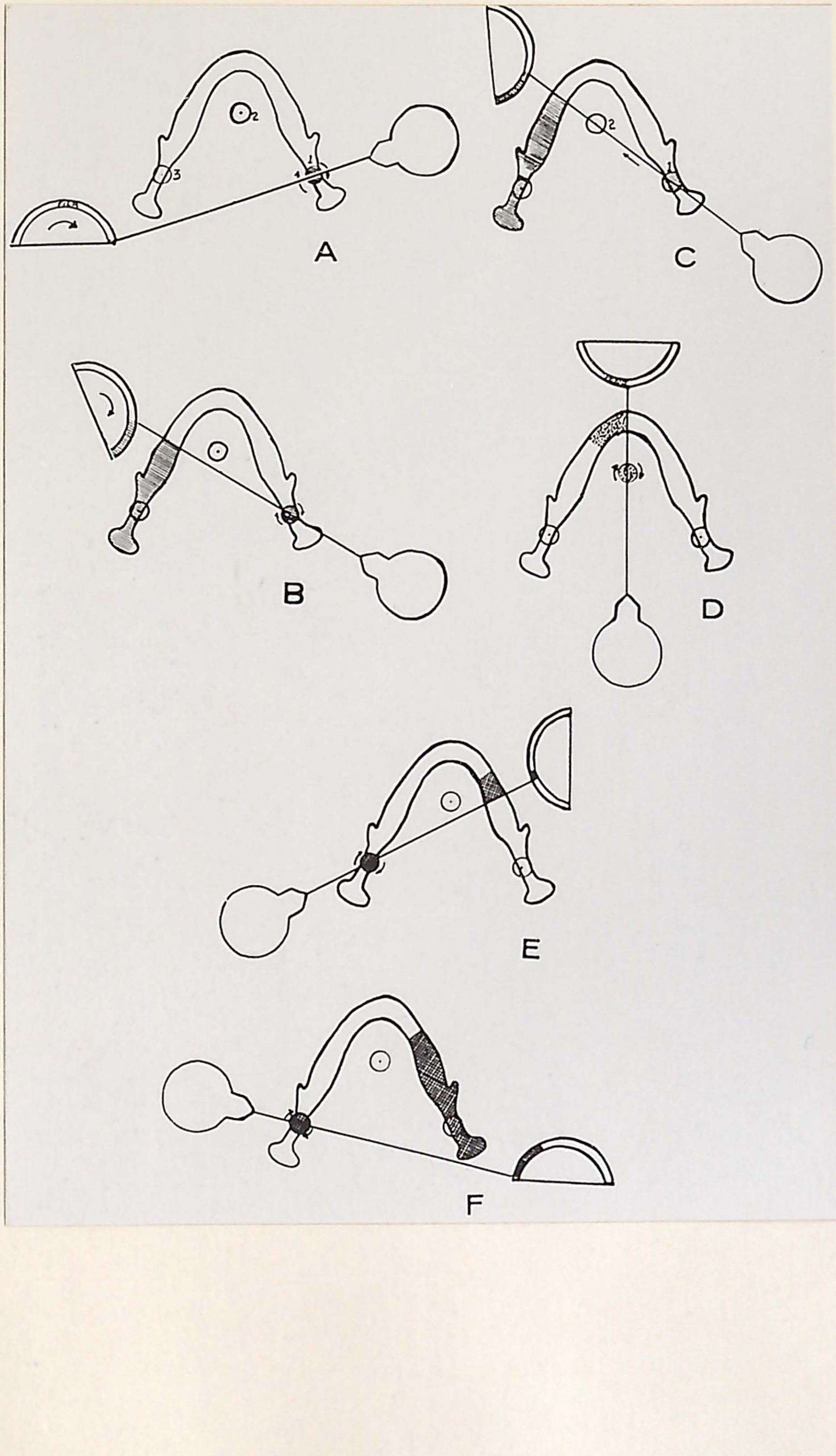

1
Lead Backing
Film
Film
Lead Backing
a
2
Lead Backing
Film
3

Figure 3. Diagrams demonstrating the relative movement of the radiation source and film in the Orthopantomograph developed by Paatero.[98]


A
C
B
D
E
F

Figures 4 and 5.

Diagrams demonstrating placement of the intraoral radiation source used with the Panoramix.[34]

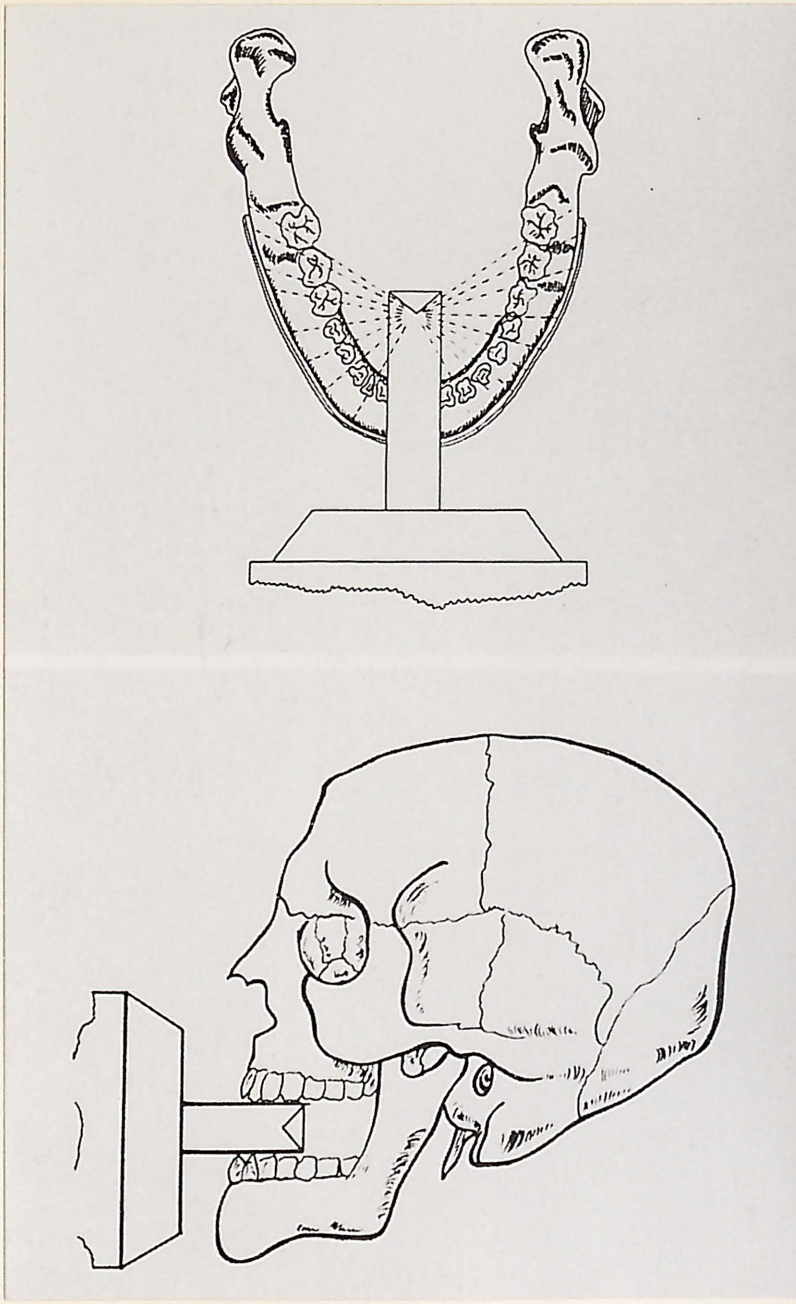


Figure 6. Diagrams demonstrating relative movement of radiation source and film in the Rotagraph pioneered by Blackman in England.[34]

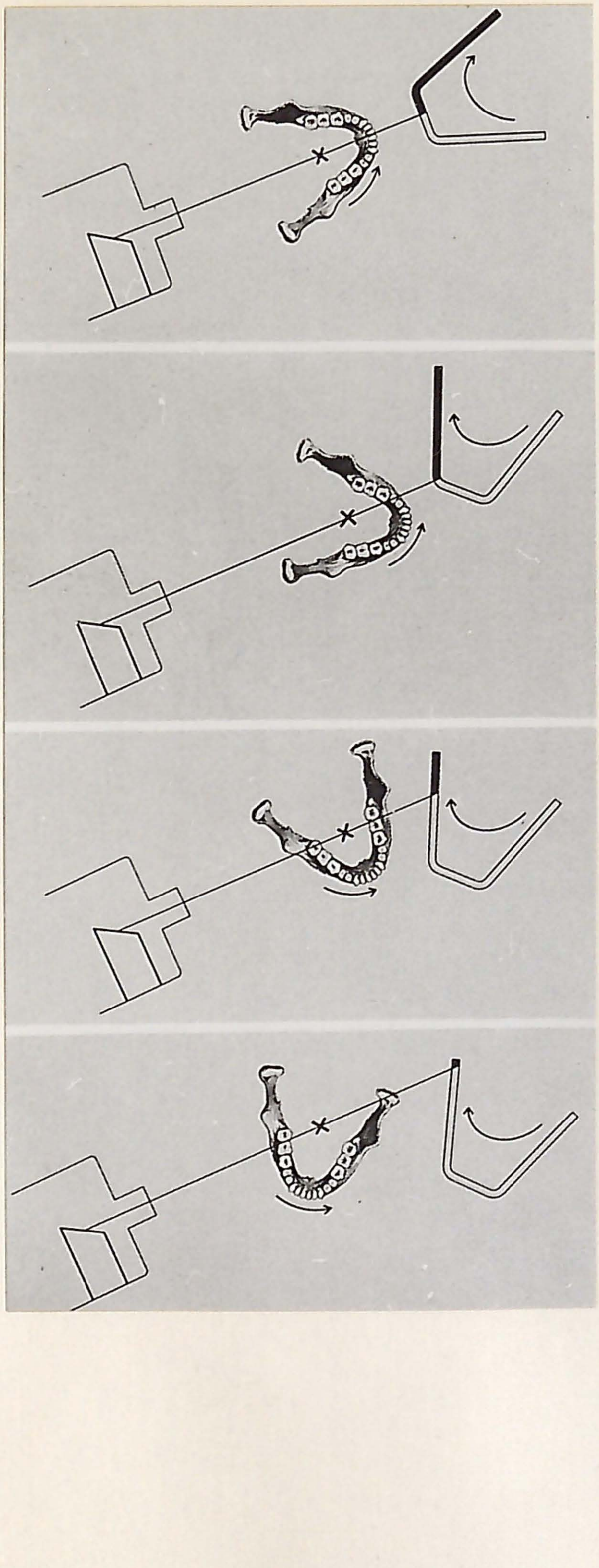
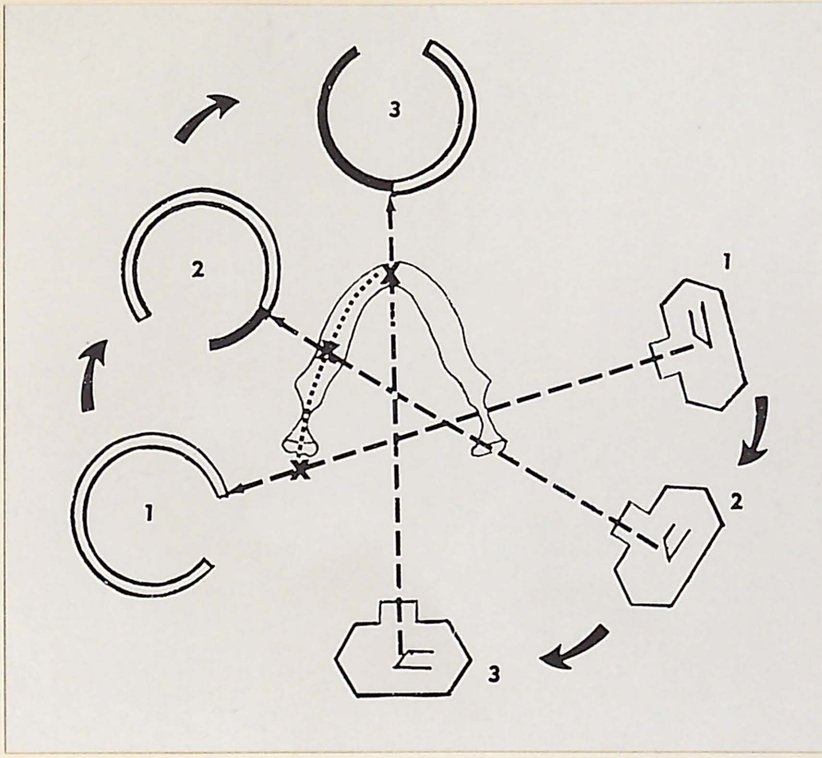


Figure 7. Diagram demonstrating relative movement of radiation source and film in the GE 3000.[30]

Figure 8. Diagram demonstrating some of the semi-elliptical paths that can be traced by the continuous axis of rotation of the GE 3000. The dotted line shows the most desirable arc.[30]


3
2
1
1
2
3

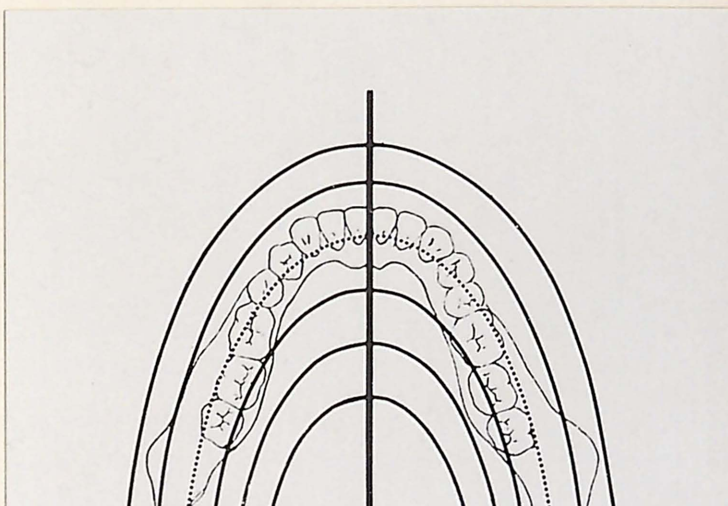


Figure 9. Labelled diagram of XRM Panorex.
1, Upward or downward movement of the horizontal arm which supports the tube head and cassette holder. 2, Movement of the tube head and cassette holder in a clockwise or counterclockwise direction. 3, Movement of the cassette within the holder; it always moves in the opposite direction to the tube travel. 4, Movement of the chin rest. 5, Movement of the chair. 6, Phase control unit (for chair 51
travel). 7, Chin rest. 8a, Foot switch. 8b, hand switch.

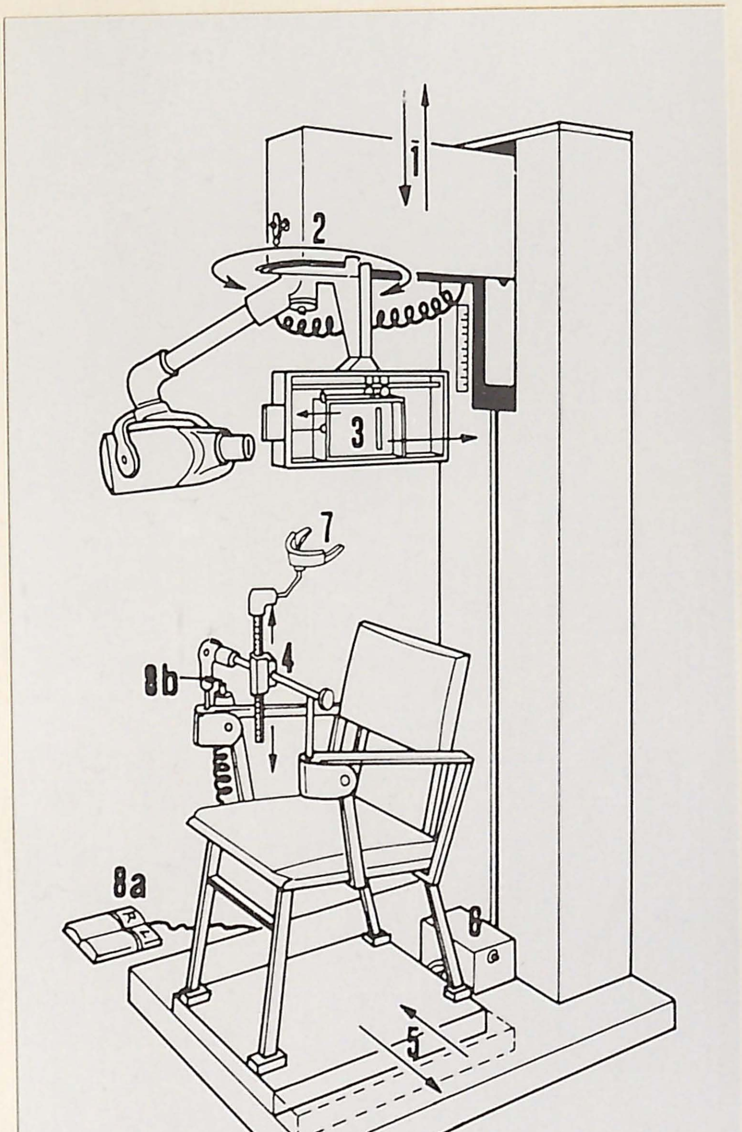

1
2
3
7
4
8b
8a
R L
6
5

Figure 10. Diagrams demonstrating relative movement of radiation source and film in the S.S. White Panorex.[34]

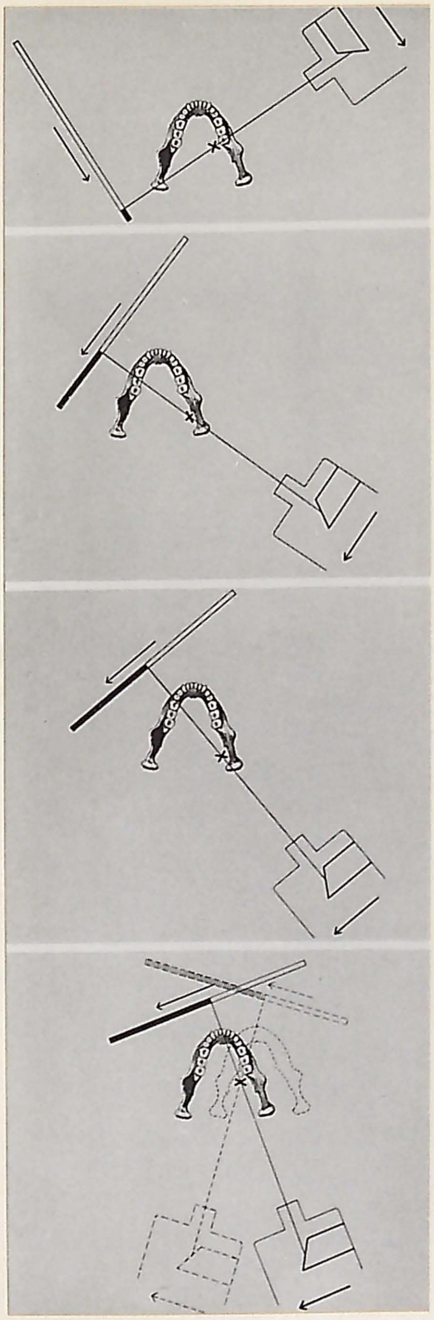
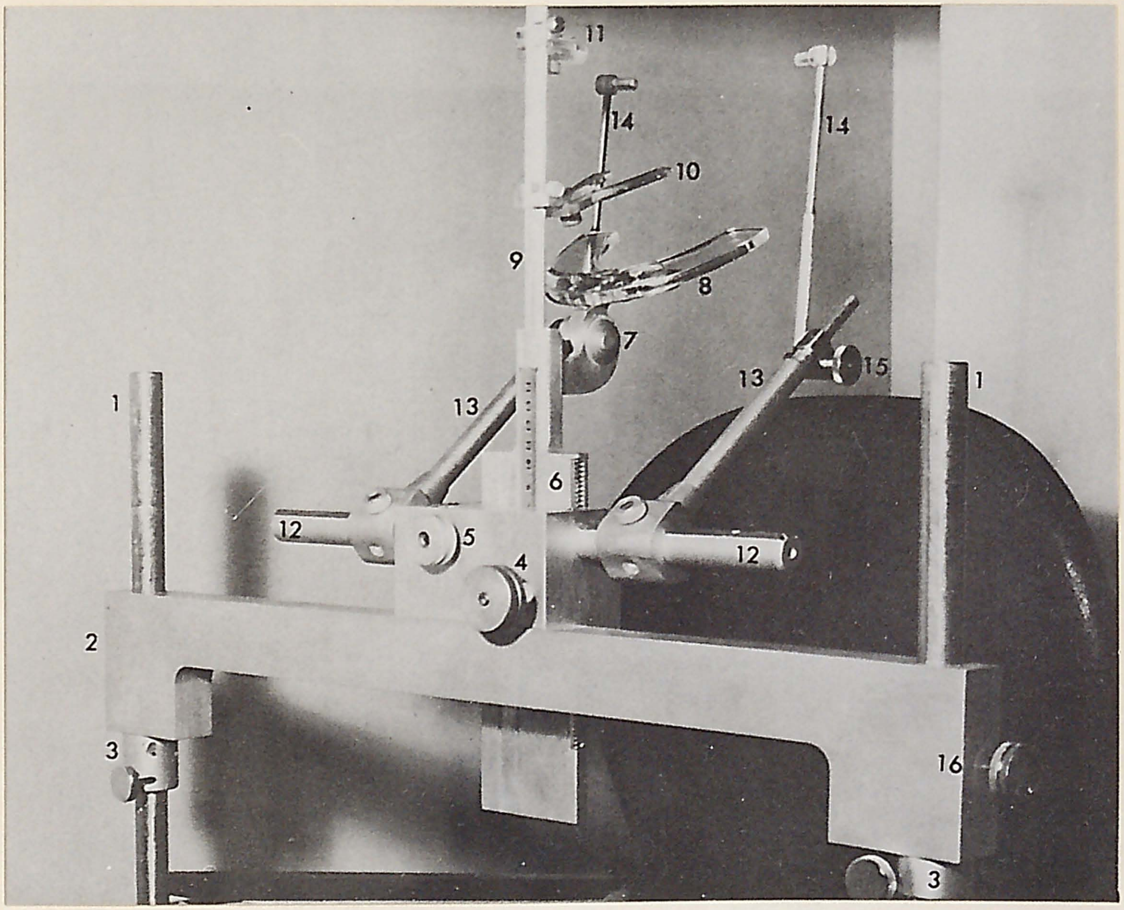


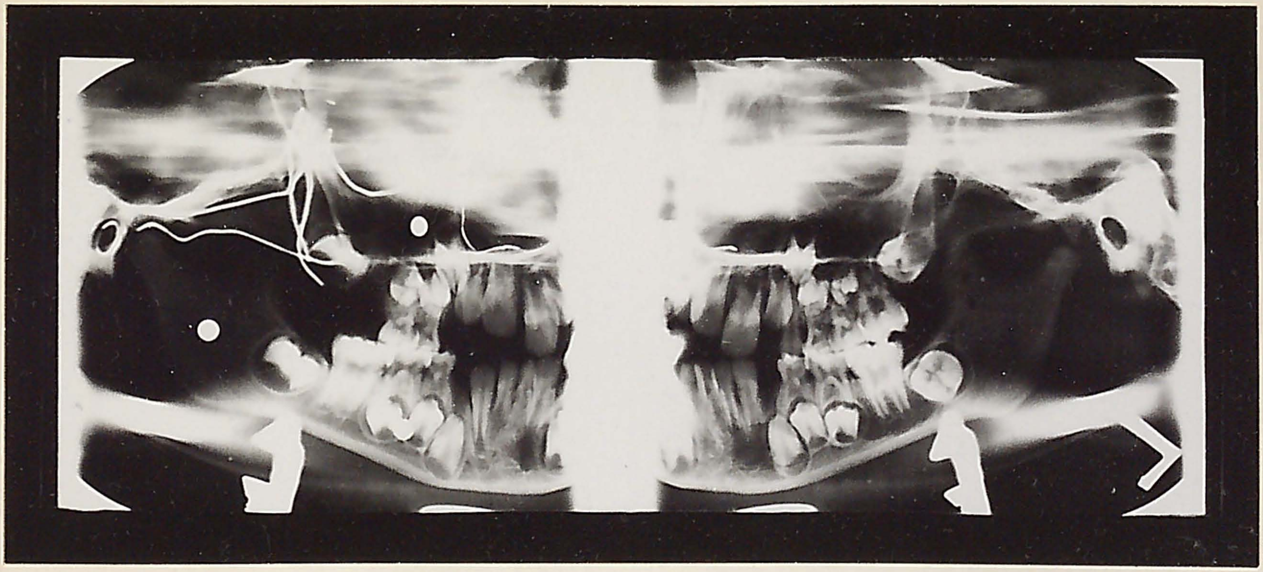
Figure 11. Photograph of cephalostat developed for use on the Panorex by Hymer.[96]



11
14
14
10
9
8
7
15
1
13
13
1
6
12
5
12
4
2
3
16
3

Figure 12. Panorex radiograph demonstrating how structures were outlined on the skull using radiopaque markers.

Figure 13. A dry skull with radiopaque markers in place is shown on a clear Plexiglas support. The support is attached to the chin rest with small "C" clamps.



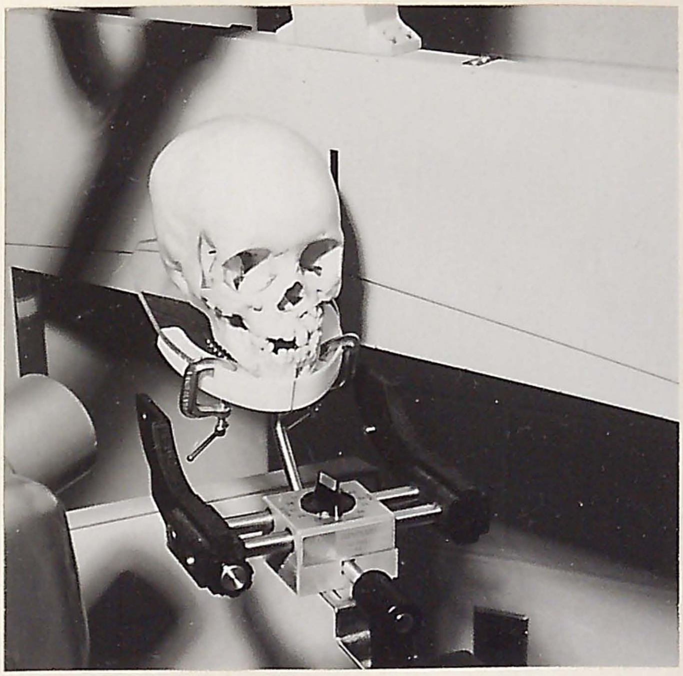
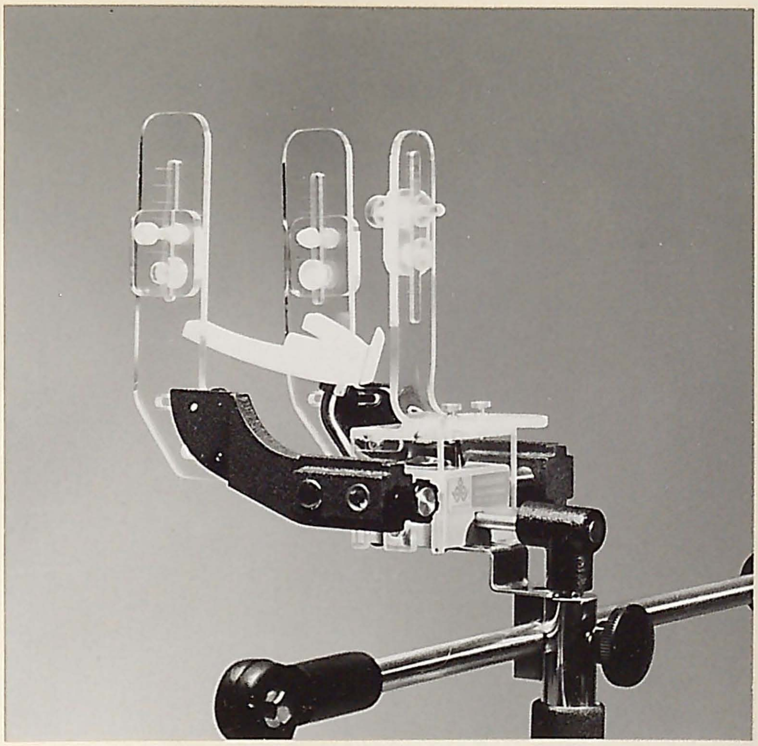


Figure 14. Photograph of the cephalostat in place on the Panorex demonstrating its parts and placement.

Figure 15. Photograph demonstrating a patient whose head has been stabilized using the cephalostat.



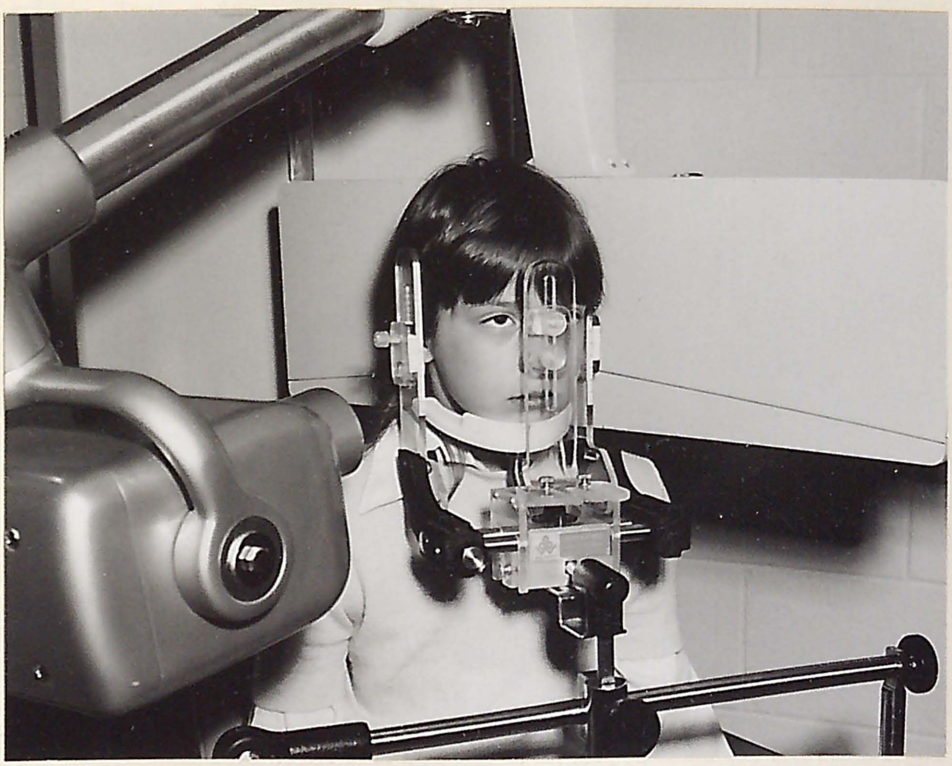
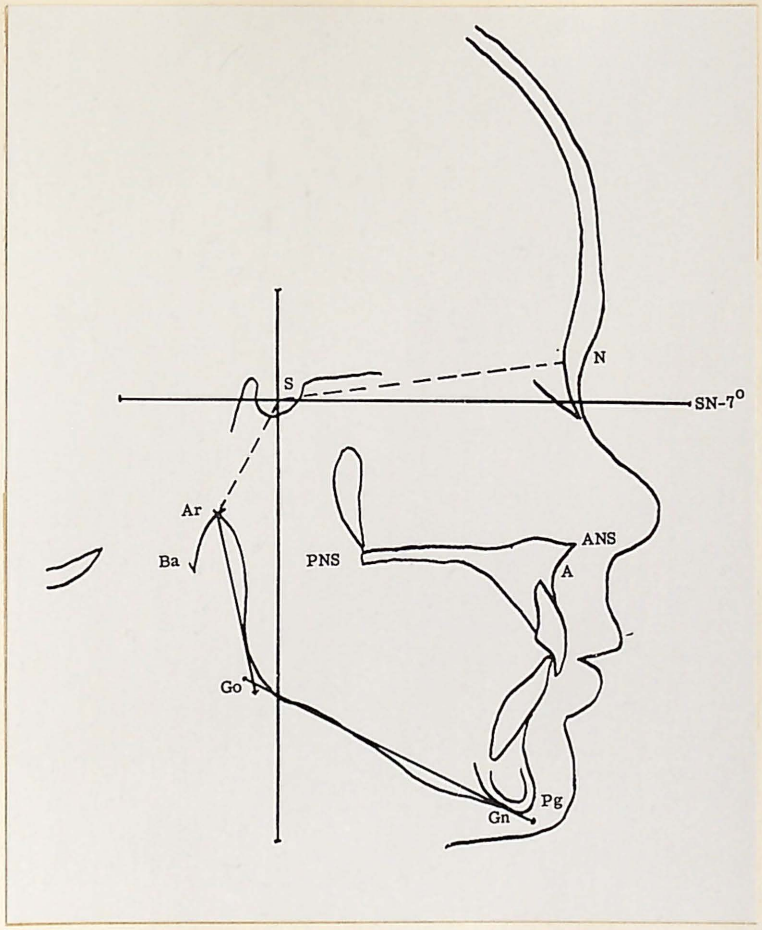


Figure 16. Diagram demonstrating a typical lateral headplate tracing.

Figure 17. Diagram demonstrating a typical tracing from a Panorex radiograph.


S
N
SN-7°
Ar
Ba
PNS
ANS
A
Go
Pg
Gn

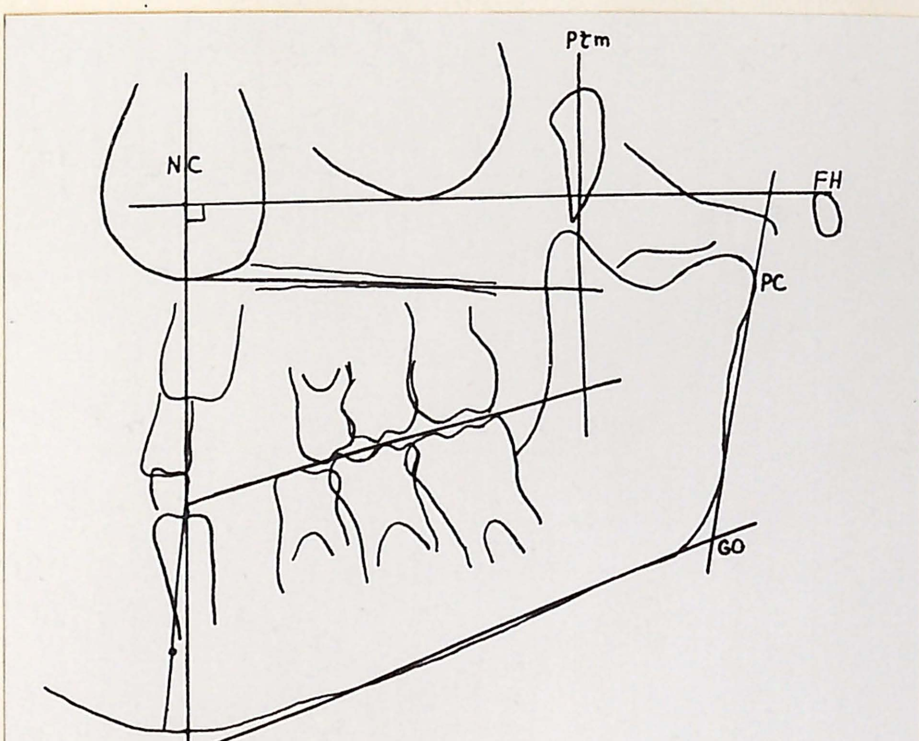

Ptm
NC
FH
PC
GO

Figure 18. Sample of the data form used by the evaluators.

Date Radiograph Taken:		
Patient Number		
Name:	Nasion Support Adjustments	Ear Rod Adjustments Left Right
Birthdate:	1. Vertical	1. Vertical
Chronologic Age:	2. Horizontal	2. Horizontal
Sex		

Measurements	Lateral Headplate			Panorex			Correction Factor
	Evaluator #1	Evaluator #2	Average	Evaluator #1	Evaluator #2	Average	
1. Length of posterior cranial base							
2. Length of body of the maxilla							
3. Effective length of mandible							
4. Absolute length of mandible							
5. Length of mandibular ramus							
6. Length of mandibular body							
7. Gonial angle							
8. Upper facial height							
9. Lower facial height							
10. Nasal floor to Frankfort horizontal							
11. Mandibular plane to Frankfort horiz.							
12. Angle of convexity							
13. Ramal plane angle							
14. Occlusal plane angle							
15. Vertical position of upper incisor							

TABLES

Table I

Evaluator Mean Measurements

	Measurements	Lateral Headplate Evaluator #1	Lateral Headplate Evaluator #2	Panorex Evaluator #1	Panorex Evaluator #2
1	Length of posterior cranial base	29.69	29.69	36.15	36.13
2	Length of body of the maxilla	46.57	46.56	58.47	58.44
3	Effective length of mandible	68.34	68.33	92.86	92.75
4	Absolute length of mandible	93.03	93.01	119.15	118.98
5	Length of mandibular ramus	38.64	38.63	47.95	47.87
6	Length of mandibular body	66.23	66.41	86.66	86.60
7	Gonial angle	129.21	129.20	124.90	124.87
8	Upper facial height	36.02	36.61	44.18	44.18
9	Lower facial height	58.64	58.65	69.18	69.23
10	Nasal floor to Frankfort horizontal	1.54	1.53	.58	.48
11	Mandibular plane to Frankfort horizontal	21.86	21.79	28.47	28.52
12	Angle of convexity	7.24	7.23	3.85	3.88
13	Ramal plane angle	76.79	76.75	79.12	79.11
14	Occlusal plane angle	11.54	11.59	12.11	12.16
15	Vertical position of upper incisor	25.21	25.23	30.15	30.06

No significant difference between evaluators' measurements was found using the Student Newman-Keul "t" test.

Table II

Comparison of the Lateral Headplate and Panorex Measurements Across the Fifteen Variables Using Paired Observations

Pair	Variable	N	Mean	Standard Deviation	Range of Differences	DF	t for Paired Data
1	1	48	29.71	2.52	-16.50 to 1.20	47	12.14
	16		36.17	3.83			
2	2	48	46.59	2.94	-24.20 to -2.40	47	14.14
	17		58.47	6.17			
3	3	48	68.36	6.94	-47.40 to -11.50	47	27.34
	18		92.83	4.66			
4	4	48	93.05	5.61	-41.80 to-14.50	47	29.12
	19		119.09	7.32			
5	5	48	38.67	3.36	-18.00 to -1.40	47	17.49
	20		47.93	4.49			
6	6	48	66.31	4.87	-41.10 to -5.80	47	22.56
	21		86.66	7.09			
7	7	48	129.23	5.61	- 5.90 to 11.40	47	8.40
	22		124.90	5.34			
8	8	48	44.19	3.44	- 70 to 17.60	47	13.36
	23		36.05	4.88			
9	9	48	58.66	4.53	-19.30 to .00	47	21.25
	24		69.23	4.16			

Table II (Continued)

Comparison of the Lateral Headplate and Panorex Measurements Across the Fifteen Variables Using Paired Observations

Pair	Variable	N	Mean	Standard Deviation	Range of Differences	DF	t for Paired Data	
10	10	48	1.54	3.19	-7.90 to 10.60	47	1.51	N.S.
	25		.54	3.91				
11	11	48	28.52	4.63	-9.60 to 13.70	47	10.55	
	26		22.06	5.05				
12	12	48	7.25	6.78	-37.60 to 51.00	47	1.35	N.S.
	27		3.86	14.20				
13	13	48	79.14	5.44	-7.60 to 12.50	47	3.59	
	28		76.78	5.78				
14	14	48	11.58	4.63	-7.40 to 7.00	47	.84	N.S.
	29		12.14	4.93				
15	15	48	25.24	2.88	-11.70 to 1.10	47	11.37	
	30		30.10	2.93				

With 47 degrees of freedom (DF) critical values of t are 2.69 at the 0.05 level of significance and 2.01 at the 0.01 level of significance. Three of the values of t were not significant (N.S.).

Table III

Comparison of the Lateral Headplate and Panorex Measurements for Males Only Across the Fifteen Variables Using Paired Observations

Pair	Variable	N	Mean	Standard Deviation	Range of Differences	DF	t for Paired Data
1	1	24	29.99	2.39	-12.20 to 1.20	23	8.54
	16		35.80	3.67			
2	2	24	47.03	3.17	-24.20 to -2.40	23	11.65
	17		59.40	5.94			
3	3	24	69.99	7.27	-47.40 to -11.50	23	16.44
	18		93.21	4.58			
4	4	24	94.14	5.55	-41.80 to -10.00	23	17.44
	19		120.05	7.75			
5	5	24	39.14	3.62	-18.00 to -1.40	23	11.11
	20		48.29	4.83			
6	6	24	67.21	4.63	-41.10 to -5.80	23	13.02
	21		87.37	7.94			
7	7	24	129.03	5.36	- 5.90 to 10.10	23	4.78
	22		125.08	5.75			
8	8	24	44.54	3.08	1.30 to 13.70	23	10.52
	23		36.52	5.21			
9	9	24	59.29	4.39	-19.30 to -5.70	23	18.38
	24		70.39	3.79			

Table III (continued)

Comparison of the Lateral Headplate and Panorex Measurements for Males Only Across the Fifteen Variables Using Paired Observations

Pair	Variable	N	Mean	Standard Deviation	Range of Differences	DF	t for Paired Data	
10	10	24	1.84	3.03	- 5.70 to 10.60	23	1.72	N.S.
	25		.30	4.52				
11	11	24	27.86	4.91	- 9.60 to 11.50	23	5.15	
	26		22.70	6.21				
12	12	24	6.12	5.99	-37.60 to 28.30	23	.83	N.S.
	27		2.67	16.90				
13	13	24	78.65	6.15	- 7.60 to 12.30	23	1.47	N.S.
	28		77.07	6.66				
14	14	24	11.41	5.10	- 9.60 to 5.60	23	1.42	N.S.
	29		12.86	5.26				
15	15	24	25.19	3.01	-11.10 to -2.20	23	11.22	
	30		30.71	2.93				

With 23 degrees of freedom (DF) critical values of t are ~~2.81~~ 2.07 at the .05 level of significance and ~~2.07~~ 2.81 at the .01 level of significance. Four of the values of t were not significant (N.S.).

Table IV

Comparison of the Lateral Headplate and Panorex Measurements for Females Across the Fifteen Variables Using Paired Observations

Pair	Variable	N	Mean	Standard Deviation	Range of Differences	DF	t for Paired Data
1	1	24	29.44	2.66	-16.50 to -.30	23	8.76
	16		36.54	4.02			
2	2	24	46.15	2.69	-23.10 to -3.30	23	8.64
	17		57.55	6.39			
3	3	24	66.73	6.34	-38.10 to -15.90	23	24.06
	18		92.45	4.80			
4	4	24	91.96	5.57	-35.00 to -14.50	23	25.41
	19		118.12	6.89			
5	5	24	38.22	3.09	-15.50 to -3.50	23	13.73
	20		47.57	4.20			
6	6	24	65.41	5.07	-30.20 to -13.50	23	21.34
	21		85.95	6.20			
7	7	24	129.43	5.96	- .40 to 11.40	23	7.55
	22		124.72	5.03			
8	8	24	43.85	3.79	- .70 to 17.60	23	8.54
	23		35.59	4.60			
9	9	24	58.03	4.66	-15.80 to 0.00	23	12.73
	24		68.07	4.29			

Table IV (Continued)

Comparison of the Lateral Headplate and Panorex Measurements for Females Across the Fifteen Variables Using Paired Observations

Pair	Variable	N	Mean	Standard Deviation	Range of Differences	DF	t for Paired Data	
10	10	24	1.24	3.38	- 7.90 to 10.10	23	.46	N.S.
	25		.79	3.27				
11	11	24	29.18	4.32	2.30 to 13.70	23	12.57	
	26		21.42	3.56				
12	12	24	8.37	7.46	- 21.50 to 37.20	23	1.16	N.S.
	27		5.06	11.11				
13	13	24	79.63	4.71	- 5.00 to 12.50	23	4.16	
	28		76.49	4.87				
14	14	24	11.75	4.21	- 7.30 to 7.00	23	.41	N.S.
	29		11.42	4.57				
15	15	24	25.30	2.81	- 11.70 to 1.10	23	6.15	
	30		29.49	2.85				

With 23 degrees of freedom (DF) critical values of t are 2.81 at the .05 level of significance and 2.07 at the .01 level of significance. Three of the values of t were not significant (N.S.).

Table V

Lateral Headplate Mean Measurements Divided By Age

	Measurements	5 Yrs.	6 Yrs.	7 Yrs.	8 Yrs.	9 Yrs.	10 Yrs.
1	Length of posterior cranial base	29.11	28.05	31.22	29.65	31.21	29.04
2	Length of body of the maxilla	45.66	46.36	46.44	47.20	47.19	46.66
3	Effective length of mandible	68.16	65.39	67.27	70.43	70.40	68.52
4	Absolute length of mandible	88.40	90.50	92.11	95.26	97.33	94.69
5	Length of mandibular ramus	36.91	38.39	38.65	38.27	40.29	39.55
6	Length of mandibular body	61.60	63.23	64.56	69.80	70.45	68.24
7	Gonial angle	132.46	130.21	131.42	127.30	126.59	127.40
8	Upper facial height	40.25	41.92	43.98	45.49	46.77	46.75
9	Lower facial height	54.70	56.58	59.14	59.11	62.16	60.27
10	Nasal floor to Frankfort horizontal	2.26	2.33	2.02	2.01	.88	- .25
11	Mandibular plane to Frankfort horizontal	26.48	29.01	29.47	28.61	28.50	29.05
12	Angle of convexity	7.18	9.50	12.31	4.51	5.30	4.67
13	Ramal plane angle	73.92	78.69	77.85	81.14	81.79	81.44
14	Occlusal Plane angle	8.96	12.06	11.53	13.80	10.81	12.34
15	Vertical position of upper incisor	24.28	24.35	24.62	25.93	26.14	26.15

All measurements are in millimeters except numbers 7, 10, 11, 12, 13 and 14, which are measured in degrees.

Table VI

Panorex Mean Measurements Divided by Age

	Measurements	5 Yrs.	6 Yrs.	7 Yrs.	8 Yrs.	9 Yrs.	10 Yrs.
1	Length of posterior cranial base	37.00	35.96	38.68	34.74	35.72	34.93
2	Length of body of the maxilla	55.35	55.76	55.36	62.35	62.20	59.82
3	Effective length of mandible	89.80	89.84	92.57	95.59	96.43	92.76
4	Absolute length of mandible	110.77	114.45	120.21	122.03	125.96	121.10
5	Length of mandibular ramus	44.75	44.59	48.33	47.64	50.02	52.26
6	Length of mandibular body	79.40	84.45	86.90	91.59	93.31	84.33
7	Gonial angle	126.10	124.41	126.71	122.46	123.51	126.21
8	Upper facial height	32.87	31.46	36.23	37.09	40.40	38.26
9	Lower facial height	64.74	67.39	69.50	69.33	71.57	72.85
10	Nasal floor to Frankfort horizontal	2.34	2.27	.78	.22	- 2.91	.56
11	Mandibular plane to Frankfort horizontal	18.21	21.49	24.95	22.15	23.54	22.05
12	Angle of convexity	11.06	4.54	- .26	- 4.54	- 3.49	15.88
13	Ramal plane angle	71.85	76.91	76.89	79.52	79.88	75.62
14.	Occlusal plane angle	8.41	11.71	14.76	12.22	12.29	13.43
15	Vertical position of upper incisor	28.41	28.84	29.56	30.31	30.68	32.80

All measurements are in millimeters except numbers 7, 10, 11, 12, 13 and 14, which are measured in degrees.

Table VII

Matrix of Correlation Coefficients Comparing the Lateral Headplate and Panorex on all Fifteen Measurements

	Variable Number														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	1.00														
2	.18	1.00													
3	.50	.64	1.00												
4	.36	.61	.76	1.00											
5	.33	.51	.62	.72	1.00										
6	.37	.46	.64	.85	.43	1.00									
7	- .16	.02	- .07	- .08	- .25	- .43	1.00								
8	.27	.06	.15	.49	.29	.58	- .29	1.00							
9	.21	.51	.42	.79	.47	.67	.05	.29	1.00						
10	.05	.51	.46	.28	.22	.13	.17	- .55	.43	1.00					
11	- .40	- .35	- .72	- .24	- .48	- .25	.45	.15	.12	- .35	1.00				
12	- .02	.17	- .48	- .48	- .21	- .48	.07	- .30	- .17	.05	.24	1.00			
13	- .18	- .33	- .54	- .12	- .15	.23	- .65	.43	.05	- .48	.39	.12	1.00		
14	- .19	- .42	- .67	- .37	- .22	- .24	- .23	.24	- .22	- .55	.47	.34	.63	1.00	
15	.06	.37	.18	.43	.35	.29	.06	.00	.67	.39	.10	.07	.02	.08	1.00

Table VII (Continued)

Matrix of Correlation Coefficients Comparing the Lateral Headplate and Panorex on all Fifteen Measurements

	Variable Number														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
16	.38	.01	-.04	-.17	-.01	-.21	.07	-.11	-.16	-.01	-.08	.35	-.14	.05	.05
17	.00	.35	.46	.69	.36	.59	.06	.27	.51	.14	-.01	-.50	-.06	-.24	.21
18	.30	.41	.49	.70	.38	.64	.02	.32	.54	.13	-.03	-.30	-.04	-.17	.30
19	.29	.25	.22	.57	.27	.64	-.17	.53	.61	-.06	.18	-.12	.33	.12	.28
20	.40	.35	.46	.56	.60	.56	-.38	.40	.52	.06	-.30	-.14	.13	-.08	.34
21	.18	.09	-.00	.31	.03	.51	-.31	.46	.33	-.14	.21	-.00	.50	.29	.06
22	-.21	-.11	-.14	-.04	-.23	-.28	.79	-.15	.15	.03	.51	-.08	-.38	-.14	.15
23	.29	.12	.18	.46	.32	.51	-.29	.53	.38	-.24	.02	-.18	.31	.12	.19
24	.26	.21	.30	.66	.42	.63	-.12	.55	.69	-.02	.11	-.27	.21	.01	.37
25	-.22	-.08	.03	-.13	-.13	-.25	.32	-.29	-.21	.18	-.04	-.11	-.37	-.26	-.09
26	-.09	-.30	-.44	-.16	-.38	-.06	.17	.24	.16	-.23	.62	.15	.35	.37	-.01
27	-.01	.14	.36	.15	.21	.08	-.03	-.10	-.03	.17	-.40	-.27	-.31	-.46	-.01
28	.08	-.12	-.24	-.07	-.08	.23	-.61	.36	.01	-.23	.06	.20	.67	.47	-.10
29	.02	-.18	-.42	-.28	-.16	-.17	-.15	.28	-.05	-.30	.31	.40	.41	.54	-.04
30	.26	.21	.32	.44	.28	.42	-.06	.41	.41	-.08	-.06	-.21	.00	.01	.48

Table VII (Continued)

Matrix of Correlation Coefficients Comparing the Lateral Headplate and Panorex on all Fifteen Measurements

	Variable Number														
	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
16	1.00														
17	-.60	1.00													
18	-.03	.79	1.00												
19	-.12	.59	.80	1.00											
20	.09	.30	.49	.60	1.00										
21	-.27	.46	.56	.82	.19	1.00									
22	.20	.03	.08	-.04	-.22	-.33	1.00								
23	-.15	.42	.49	.65	.53	.55	-.25	1.00							
24	-.15	.43	.45	.64	.53	.37	.12	.33	1.00						
25	.17	-.27	-.36	-.63	-.34	-.73	.41	-.66	-.09	1.00					
26	-.08	-.08	-.04	.38	-.20	.49	.33	.11	.25	-.30	1.00				
27	.17	-.14	-.19	-.43	.22	-.68	.02	-.23	-.02	.54	-.63	1.00			
28	-.28	-.05	-.06	.40	.07	.74	-.67	.35	.13	-.65	.44	-.55	1.00		
29	.05	-.25	-.15	.29	.02	.42	-.06	.15	.17	-.42	.68	-.59	.59	1.00	
30	.05	.14	.20	.29	.35	.05	.20	.14	.69	.14	.17	.13	-.05	.14	1.00

Sample size 48 in all comparisons.

Variables No. 1-15 are lateral headplate and variables No. 16-30 are Panorex.

A correlation coefficient of ± .71 is considered the lowest acceptable level for purposes of this study.

Table VIII

Spearman Rho Rank Order Correlation of Tracing Error Comparing Duplicate Tracings of Eight Panorex Radiographs to the Original Tracing by the Same Evaluator.

	Measurements	ΣD^2	ρ
1	Length of posterior cranial base	2.0	.98
2	Length of body of the maxilla	2.5	.97
3	Effective length of mandible	6.0	.93
4	Absolute length of mandible	8.5	.90
5	Length of mandibular ramus	24.0	.71
6	Length of mandibular body	4.0	.95
7	Gonial angle	6.0	.93
8	Upper facial height	4.0	.95
9	Lower facial height	19.5	.77
10	Nasal floor to Frankfort horizontal	57.5	.32
11	Mandibular plane to Frankfort horizontal	2.0	.98
12	Angle of convexity	24.0	.72
13	Ramal plane angle	8.0	.90
14	Occlusal plane angle	9.0	.89
15	Vertical position of upper incisor	22.5	.73

.001 level of significance used

A ρ of .90 or above is desirable.

A ρ of at least .71 is considered acceptable because at least 50% of the variance can be accounted for. The low correlation of measurement "10" can be accounted for partially by difficulty in measuring accurately and the small deviation between samples.

Table IX

Spearman Rho Rank Order Correlation of Measurements from Tracings of Eight Duplicate Pairs of Panorex Radiographs Demonstrating Head Position Reproducibility Using a Cephalostat

	Measurements	ΣD^2	ρ	
1	Length of posterior cranial base	22	.74	
2	Length of body of the maxilla	16	.81	
3	Effective length of mandible	50	.41	N.S.
4	Absolute length of mandible	55.5	.34	N.S.
5	Length of mandibular ramus	20	.73	
6	Length of mandibular body	28	.67	
7	Gonial angle	8	.90	
8	Upper facial height	91	- .09	N.S.
9	Lower facial height	6	.93	
10	Nasal floor to Frankfort horizontal	16.5	.80	
11	Mandibular plane to Frankfort horizontal	28	.67	
12	Angle of convexity	22	.74	
13	Ramal plane angle	16	.81	
14	Occlusal plane angle	38	.55	
15	Vertical position of upper incisor	64	.24	N.S.

A ρ of ± .47 or above is significant at the .05 level.
Four values of ρ were not significant (N.S.).
For clinical purposes a ρ of .71 or above is acceptable.

DISCUSSION

Since studies similar to this one do not exist, it is impossible to make comparisons to other investigations. Other researchers have measured distortion in general as applied to Panorex radiography. None has established whether linear and angular measurements as applied to a Panorex tracing would be valid in a comparison to measurements from a tracing of the same patient's lateral headplate. No one has even established which measurements could be taken from a Panorex tracing.

It was determined that means of similar measurements by each evaluator were very close. In analyzing the statistics, it was thus justifiable to use the average of the two measurements as the definitive measurement value. The measurements compared in all but one instance to within .2 mm. In the one exception the difference was only .6 mm. Both the angular and linear measurements were recorded for purposes of this study to the nearest tenth of a millimeter. However, the data may be correct only to the nearest quarter or half millimeter. This is due to several variables, including the width of the line traced on the acetate paper. Even though pencils were kept sharp for tracing purposes, it was still difficult to have a thin line for every tracing. Also, differences in placement of the graph paper and protractor had a bearing on whether the measurements of the two evaluators were identical.

Table II shows that a close relationship did not exist between similar measurements on each technique when compared across the fifteen variables. This was not unexpected. Numerous studies have demonstrated that due to enlargement in the Panorex technique, the structures on the Panorex radiograph would be expected to show a positive distortion or enlargement in comparison to the lateral headplate. In all but one instance the measurements from the Panorex technique were larger than the corresponding measurements from the lateral headplate. This one instance of difference can be explained by the fact that the anatomic landmarks used for the initial measurement on the Panorex were different from those used on the lateral headplate; therefore, all of the initial measurements were much smaller to begin with. All but one of the angular measurements showed a reduction in size on the Panorex as compared to the lateral headplate. The reduction in size of the angles may be explained by the fact that the Panorex tube head does not radiograph the head directly from the side and parallel to the floor but is angled upward 5° from horizontal. The 5° angulation upward would have the effect of closing the inside of the angles and making them appear smaller. So, although linear measurements on the Panorex show an enlargement when compared to the lateral headplate, angular measurements are less than their lateral headplate counterpart.

Three of the t values in Table II showed that a significant difference was not demonstrated between the two measurements. Two of the three measurements had such large ranges that it would be difficult to use the measurement reliably. Although significant differences were not demonstrated, it still cannot be said that the two measurements are similar or interchangeable -- not on an individual patient basis, at any rate.

Separation of the data into male and female samples, again comparing the lateral headplate to the Panorex across the fifteen variables, was useful in that it proved that there was no significant difference in the t values for the comparisons of the measurements due to variations in the sex of the individuals. It would be difficult to substantiate differences due to sex, even if there were a considerable difference in the t values for one or the other samples when divided by sex, since the samples in each age group were so small.

Tables V and VI demonstrated the lateral headplate and Panorex mean measurements divided by age groups. Mean measurements for each variable increased or decreased progressively each year as the children grew older, except for the ten-year-olds. A possible explanation for this could be that the universe from which the sample was selected was a select universe made up of children who were all in the Graduate Pedodontic Clinic due to having unique dental problems. The sample population could not be expected to be a random sample of all children in each age group and thus did not necessarily conform in or within each age group, as in a true random sample of the entire population for children of these ages. The entire sample consisted of only 48 children, which when evenly divided according to age and sex, gave twelve groups of four children. That sample size was too small to give any more than an indication in making comparisons between age groups. It might have been more informative to concentrate on children in a two or three year age span and then increase the sample size for each age and sex group.

The most interesting information was provided in Table VII, the matrix of correlation coefficients. The correlation coefficients in this Table compared not only within-technique variations for the Panorex and lateral headplate, but compared the lateral headplate to the Panorex on all fifteen measurements. Although there was a significant correlation between similar measurements in the two techniques, the data demonstrate that the differences in the two techniques are due to more than just enlargement. The exact cause of the differences, however, is not pinpointed.

Other investigators have demonstrated that a variable amount of distortion exists in the Panorex technique. This variable distortion could offer one possible explanation for the differences. The amounts of distortion vary from point to point on the Panorex in both horizontal and vertical dimensions. The difference could also be due to the fact that the point-to-point measurements that were established on the Panorex for purposes of this study might not have been the most reliable landmarks for comparison to similar points on the lateral headplate. Perhaps two other point-to-point measurements or use of other landmarks might have had a better correlation to the lateral headplate. It does demonstrate again that there is a significant correlation between similar measurements in the two techniques for the sample as a whole, but the technique is not discriminating enough to be useful on an individual patient basis.

For purposes of this study, it was considered advisable to determine whether the landmarks and structures on the tracings of the Panorex radiographs could be accurately reproduced on a second tracing of the same Panorex. For this purpose eight Panorex radiographs were selected from the total sample. The eight were marked so that the evaluator did not know whose Panorex was being traced. These eight Panorexes were traced a second time and fifteen measurements were again recorded and compared to the original set of measurements. The tracing error did not prove to be significantly different between the two sets of tracings. Differences found in the second tracing could be attributed in part to the fact that the examiner knew it was a duplicate tracing and thus took a more careful look while tracing the radiograph. In addition, since the second tracings were done with the evaluator at a considerably more advanced level of radiographic interpretation, he was able to read the radiographs better and so presumably make a more accurate tracing.

There appeared to be a substantial difference in the two tracings when superimposed and observed visually. The statistical comparison of the measurements, however, revealed that the tracing error was within the realm of acceptability. This stresses the importance of doing a statistical comparison and not jumping to conclusions on the strength of first impressions.

A cephalostat used by Diers was modified for use with human subjects in this study. No simple, inexpensive method of reproducing exact patient head position in the Panorex has been developed. It was thought that the cephalostat in its present form could be used to center and stabilize patients, allow a more accurate, undistorted image to be projected and create a reproducible head position making serial studies possible. A duplication of head position would be important in taking serial radiographs for establishing a growth prediction or for evaluating treatment results. The cephalostat did prove very useful for keeping the heads of the children still, especially for those in the younger age groups. The cephalostat was calibrated and thus allowed exact repositioning of the cephalostat, its ear rods, and nasion support. Although the cephalostat could be repositioned exactly, a number of variables made exact duplication of head position difficult. No record was kept as to direction of travel of tube head and cassette so that the same direction of travel could be duplicated. However, it is not known whether the tube head traveling in the opposite direction would make any difference. The cephalostat, made of Plexiglas, was not completely rigid and the patient could forcibly bend the Plexiglas by moving the head. All of the patients had their heads positioned with a cotton roll placed between their incisors. This resulted in a variable position, since the children bit into the cotton with different degrees of force. Use of a hard bite tab of some type would have helped eliminate this problem.

This study revealed a number of points that bear further investigation. A bite fork for exact repositioning,as used in some cephalostats, was not made for this study due to its impracticability in children going through rapid mixed dentition changes. Consideration should be given, however, to using some type of bite tab or bite plane to help duplicate the same cant of the occlusal plane for each patient. This would help in reliable patient repositioning and thus reduce inconsistencies.

It would be interesting to determine the effect of different occlusal plane cants on the measurements. This could be done by taking a series of Panorex radiographs on a dry skull with the occlusal plane positioned at different angulations relative to horizontal. Angular and linear measurements could be taken from tracings of each Panorex and compared to evaluate the effect of occlusal plane changes on the measurements.

A metal marker could be placed in the nasion support and would help establish a more secure nasion equivalent on the Panorex tracings.

The radiographs from the study sample could be used in a retrogressive determination to compare measurements from the lateral headplate with measurements for each of the fifteen areas on the Panorex and thus discover which similar radiographic landmarks on the Panorex best match those from the lateral headplate.

SUMMARY AND CONCLUSIONS

The purpose of this study was to determine whether angular and linear measurements from tracings of a Panorex radiograph provide a valid comparison to bony relationships identified on the lateral cephalometric headplate of the same individual.

A pilot study was performed on a dried skull to identify selected skeletal landmarks on Panorex radiographs. Using these landmarks, fifteen measurements of bony relationships of the head were completed on each radiograph. Values obtained on a lateral headplate were compared with measurements on the same patient's Panorex radiograph for a group of forty-eight patients.

The data were recorded on standard IBM punch cards and submitted for statistical analysis to the Research Computation Center of Indiana University-Purdue University at Indianapolis.

A correlation analysis was performed on the measurements of the fifteen variables of the two techniques. In twelve of the fifteen measurements the correlation was less than .71. The data were further divided according to the patient's sex but this did not significantly alter the above findings.

Enlargement in the Panorex ranged from 19 to 35 percent larger for linear measurements and 4 to 65 percent smaller for angular measurements.

A matrix of correlation coefficients compared within and between technique variations. Although a significant correlation existed between similar measurements in the two techniques, the differences were large enough to keep the Panorex technique from being clinically useful. The data demonstrated that the differences in the two techniques were not attributable only to enlargement. However, the exact cause of the differences could not be identified.

The data support the conclusions that angular and linear measurements from a tracing of a Panorex radiograph cannot be compared directly or in a proportional manner to similar measurements from a tracing of a lateral headplate of the same individual. Although there was significant correlation of comparative measurements for the sample group as a whole, there was wide variation from individual to individual.

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December, 1972	"Panorex Radiography" - Advanced Pedodontics Guest Lecture - Indiana University School of Dentistry, Indianapolis, Indiana.
January, 1973	"Graduate Pedodontic Study from a Student's Perspective" - Indiana State Society of Pedodontics, Indianapolis, Indiana.

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ABSTRACT

The Significance of Skeletal and Dental Measurements Obtained From A Panorex Radiograph

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The purpose of this study was to determine whether angular and linear measurements from tracings of a Panorex radiograph provide a valid comparison to bony relationships identified on the lateral cephalometric headplate of the same individual.

A pilot study was performed on a dried skull to identify selected skeletal landmarks on Panorex radiographs. Using these landmarks, fifteen measurements of bony relationships of the head were completed on each radiograph. Values obtained on a lateral headplate were compared with measurements on the same patient's Panorex radiograph for a group of forty-eight children.

The data were recorded on standard IBM punch cards and submitted for statistical analysis to the Research Computation Center of Indiana University-Purdue University at Indianapolis.

The data support the conclusion that angular and linear measurements from a tracing of a Panorex radiograph cannot be compared directly or in a proportional manner to similar measurements from a tracing of a lateral headplate of the same individual. Although there was significant correlation of comparative measurements for the sample group as a whole, there was wide variation from individual to individual.